EXTENSION OF ROAD TEST PERFORMANCE CONCEPTS

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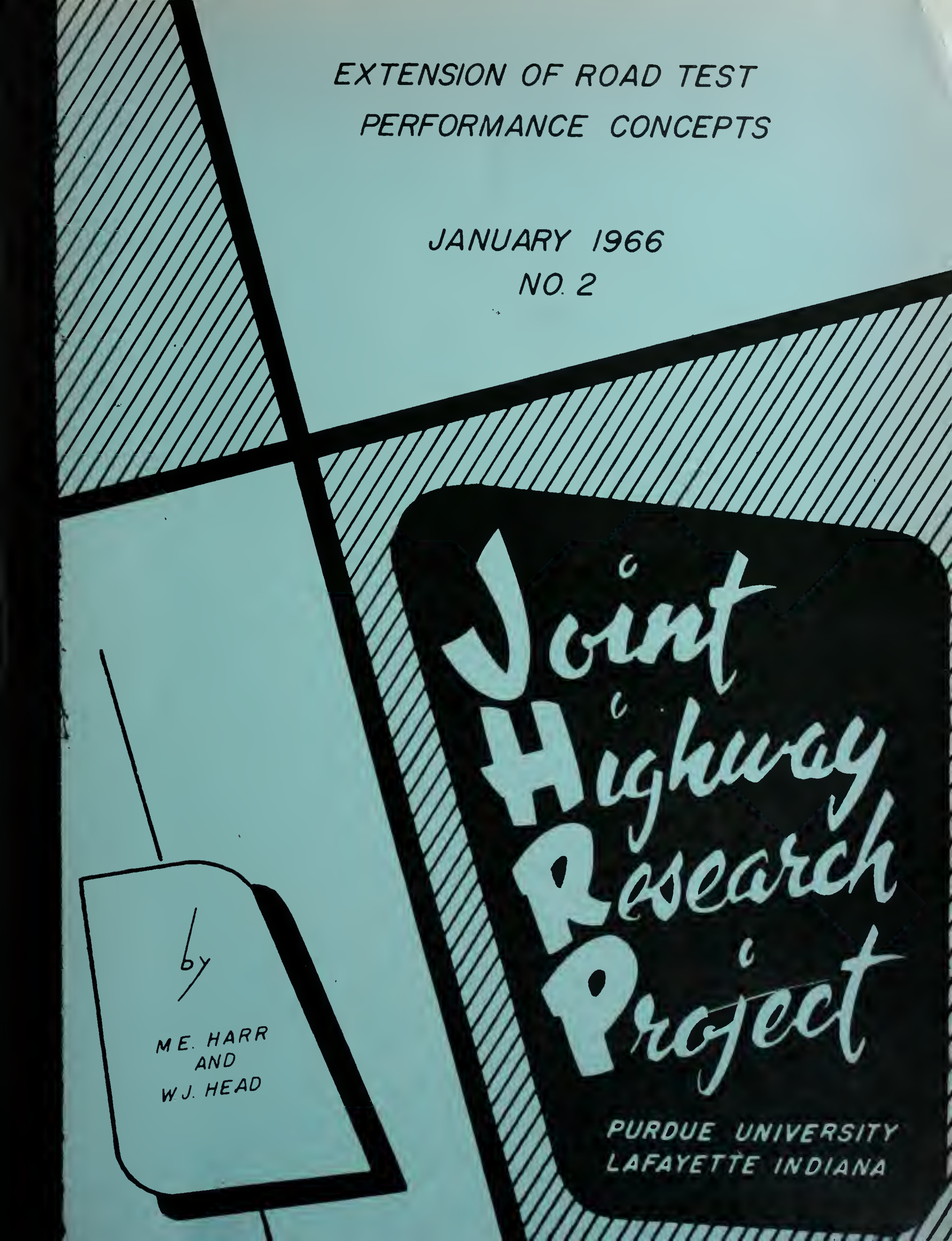

by

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Informational Report

EXTENSION OF ROAD TESTING PERFORMANCE CONCEPTS

February 11, 1966

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To: G. A. Leonards, Director
Joint Highway Research Project

From: H. L. Michael, Associate Director
Joint Highway Research Project

Attached is a copy of a report entitled "Extension of Road Testing Performance Concepts" prepared by Professor Milton E. Harr and Mr. W. J. Head.

The work reported here was sponsored through the National Cooperative Highway Research Program, Project 1-4(2). The report analyzes certain data collected at the AASHO Road Research Project at Ottawa, Illinois from a mechanistic standpoint. The analysis indicates that pavement performance as measured by the trend of the present serviceability index (PSI) with increasing axle applications is functionally related to stresses and normalized deflections.

This report is presented to the Board for information only and has not been reviewed or released by the Highway Research Board.

Respectfully submitted,

H. L. Michael

H. L. Michael, Secretary

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Final Report

on

EXTENSION OF ROAD TEST PERFORMANCE CONCEPTS

by
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and

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NCHRP Project 1-4(2)

Submitted to

Highway Research Board

by

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TABLE OF CONTENTS

Page

LIST OF FIGURES iv

LIST OF TABLES vi

LIST OF SYMBOLS vii

SUMMARY viii

INTRODUCTION 1

RESEARCH APPROACH 5

Phase 1 - Survey and Review of Literature 5
Phase 2 - Cataloging of Existing Theories and Design Procedures 5
Phase 3 - Checking Reliability of Theory in Light of the AASHO Road Test 7

FINDINGS 11

General 11
Major Findings 13
Minor Findings 16

CONCLUSIONS 17

SUGGESTED RESEARCH 19

ACKNOWLEDGEMENTS 20

REFERENCES 21

APPENDIX A: FIGURES 23

APPENDIX B: TABLES 47

APPENDIX C: BIBLIOGRAPHIC ABBREVIATIONS AND CODING SYSTEM SYMBOLS 56

APPENDIX D: CODIFIED LITERATURE 65

APPENDIX E: PROJECT STATEMENT AND RESEARCH PROSPECTUS 191

LIST OF FIGURES

Page

1. Points in the Pavement at which Stresses and Deflections Were Computed. . . . . Appendix A-1
2. Weighted Number of 6,000 Pound Single Axle Applications Versus Vertical Normal Stress. A-2
3. Weighted Number of 18,000 Pound Single Axle Applications Versus Vertical Normal Stress. A-3
4. Weighted Number of 30,000 Pound Single Axle Applications Versus Vertical Normal Stress. A-4
5. Weighted Number of 6,000 Pound Single Axle Applications Versus Radial-Vertical Shear Stress. A-5
6. Weighted Number of 18,000 Pound Single Axle Applications Versus Radial-Vertical Shear Stress. A-6
7. Weighted Number of 30,000 Pound Single Axle Applications Versus Radial-Vertical Shear Stress. A-7
8. Weighted Number of 6,000 Pound Single Axle Applications Versus Normalized Vertical Deflection. A-8
9. Weighted Number of 18,000 Pound Single Axle Applications Versus Normalized Vertical Deflection. A-9
10. Weighted Number of 30,000 Pound Single Axle Applications Versus Normalized Vertical Deflection. A-10
11. Schematic Diagram Showing Relative Position of Assumed Point . . A-11
12. Weighted Number of 6,000 Pound Single Axle Applications Versus Vertical Normal Stress. A-12
13. Weighted Number of 18,000 Pound Single Axle Applications Versus Vertical Normal Stress. A-13
14. Weighted Number of 30,000 Pound Single Axle Applications Versus Vertical Normal Stress. A-14
15. Weighted Number of 6,000 Pound Single Axle Applications Versus Normalized Vertical Deflection. A-15
16. Weighted Number of 18,000 Pound Single Axle Applications Versus Normalized Vertical Deflection. A-16
17. Weighted Number of 30,000 Pound Single Axle Applications Versus Normalized Vertical Deflection. A-17

LIST OF FIGURES (Concluded)

Page

18. Weighted Number of 18,000 Pound Single Axle Applications Versus Vertical Normal Stress (Arithmetic Plot) A-18

19. Weighted Number of 18,000 Pound Single Axle Applications Versus Radial-Vertical Shear Stress (Arithmetic Plot). A-19

20. Unweighted (Actual) Number of 18,000 Pound Single Axle Applications Versus Vertical Normal Stress (Arithmetic Plot). A-20

21. Weighted Number of 18,000 Pound Single Axle Applications Versus Vertical Normal Stress Predicted by Three-Layer Theory A-21

22. Weighted Number of 18,000 Pound Single Axle Applications Versus Ratio of Stresses (Arithmetic Plot) A-22

23. Weighted Number of 18,000 Pound Single Axle Applications Versus Ratio of Stresses (Arithmetic Plot) A-23

LIST OF TABLES

Page

1. Number of Axle Applications and Computed Stresses and Normalized Deflections (Top of Embankment) for the 6,000 Pound Single Axle Load, Loop 2, Lane 2, Design 1, AASHO Road Test . . . . . Appendix B-1

2. Number of Axle Applications and Computed Stresses and Normalized Deflections (Top of Embankment) for the 18,000 Pound Single Axle Load, Loop 4, Lane 1, Design 1, AASHO Road Text B-3

3. Number of Axle Applications and Computed Stresses and Normalized Deflections (Top of Embankment) for the 30,000 Pound Single Axle Load, Loop 6, Lane 1, Design 1, AASHO Road Test B-5

LIST OF SYMBOLS

Symbol	Meaning
F_B	Boussinesq vertical normal stress, shear stress, or normalized deflection
c	Cohesion - intercept of the Mohr rupture envelope on the shear stress axis
μ	Poisson's ratio
N_u	Number (unweighted or actual) of axle applications
N_w	Number (weighted) of axle applications
ϕ	Tan^{-1} of the Mohr rupture envelope
PSI	Present serviceability index
psi	Pounds per square inch
σ_Z	Boussinesq vertical normal stress
σ_{Z_1}	Boussinesq vertical normal stress at the top of embankment and beneath the center line of a dual tire assembly
σ_{Z_2}	Boussinesq vertical normal stress at the top of embankment and beneath the center of one tire of a dual tire assembly
$\sigma_{Z3\text{-}L}$	Vertical normal stress predicted by three-layer theory at the top of embankment beneath the center of a circular contact area
τ_{rZ}	Boussinesq radial-vertical shear stress at the top of embankment and beneath the center line of a dual tire assembly
U, V	Parameters relating Nw to F_B
$W_Z E$	Boussinesq normalized vertical deflector
$W_{Z_1} E$	Boussinesq normalized vertical deflection at the top of embankment and beneath the center line of a dual tire assembly
$W_{Z_2} E$	Boussinesq normalized vertical deflection at the top of embankment and beneath the center of one tire of a dual tire assembly

SUMMARY

Pavement performance, defined as the trend of PSI (present serviceability index) with increasing axle applications, was found to be functionally related at the AASHO Road Test to stresses and displacements. The well-known Boussinesq solution was used in the determination of stresses and normalized deflections. A more sophisticated (although not necessarily more correct) multi-layer theory was found to be no more useful than the simple Boussinesq solution in determining the relationships between stresses, displacements, and performance.

Plots of weighted number of axle applications versus stresses and normalized deflections disclosed the following approximate relationship:

$$N_W = UF_B^{\,V}$$

where:

N_W = weighted number of axle applications

F_B = Boussinesq vertical normal stress, shear stress, or normalized deflection

U,V = parameters (functions of F_B and PSI)

The precise form of the above equation was not determined due, at least in part, to a large amount of scatter in the data. Possible reasons for data scatter were considered to include the following:

1. the subjective nature of the PSI concept and the relative sensitivity of PSI to F_B;

2. the quantitatively unknown effect of seasonal and diurnal changes on AASHO Road Test pavements;

3. the dissimilar behavior of a number of replicate pavement sections at the AASHO Road Test;

4. the lack of complete data on those pavement sections which did withstand the entire Road Test program

No relationships were found between N_w and F_B for thin pavements subjected to the 6,000 lb. single axle load. Adverse ambient conditions were believed to have played a major role in the rapid failure of such pavements.

In an attempt to provide a firm basis for extrapolation of data, it was assumed that the embankment (that material whose composition and thickness was constant and common to all AASHO Road Test pavements) could withstand one axle application before falling to some undetermined, but low, PSI. Accordingly, in a number of the graphs, a point was plotted whose coordinates were "(maximum F_B occurring under one tire, 1)." These points were found to be essentially collinear with points three decades above (double logarithmic plots) in the main bodies of the graphs. In addition, little deviation in the relationships between N_w and F_B occurred if the ordinates of the points were assumed to be, say, ten instead of unity. In addition to greatly enhancing the basis for possible data extrapolation, these facts helped support the major hypothesis of the research; namely, that performance and theoretical stresses and/or deflections were functionally related.

Plots involving N_w and stress predicted by three-layer theory were analyzed but proved no more definitive than those involving stresses predicted by the homogeneous Boussinesq solution.

It was found that at the present state of the art, material parameters are poorly defined and little is known about changes in these parameters with time and ambient conditions. Because material parameters are the means by which test results can be extended to other locations on a rational basis, it is most important that work be done to define and determine these parameters and to assess

their changes under various loading, diurnal, and seasonal conditions. This work is considered a most necessary first step in extending AASHO Road Test results to other locations where conditions (loads, materials, climate) differ from those at Ottawa.

INTRODUCTION

The objectives of Project 1-4(2) are found in the project statement and are as follows:

> "To examine existing hypotheses and to develop new hypotheses of pavement performance as related to fundamental principles of engineering mechanics and materials science and to test these hypotheses with data at hand from the AASHO Road Test and elsewhere."

It was not anticipated that all objectives would be met under terms of the present contract. Several hypotheses have, however, been examined in some detail with the hope that pavement performance could be approached from a mechanistic, in contrast to a statistical, point of view. It is believed that extension of Road Test performance concepts must come from a mechanistic approach if the concepts are to have general application. The alternative is to continue testing, e.g., the Satellite Testing Program, probably on a smaller scale than the AASHO Road Test, at all those locations where conditions (climate, materials, type and frequency of loading, etc.) differ from those at Ottawa. In addition, more tests would be needed if pavements or paving materials were modified or if it became necessary to predict performance for some presently unforeseen condition. Clearly, then, a mechanistic view of pavement performance is both desirable and necessary.

The prediction of the performance of pavements (and their subsequent design) has been based largely on theories which either contain serious limitations, have been at best only partially verified, or are significantly altered in their application by empirical factors. At the present level of knowledge, the profession knows of no theory that will adequately and reliably predict the performance of pavements.

Inherent in the problem of predicting pavement performance is perhaps the more fundamental problem of defining pavement failure. At least two types of failure are recognized; these are structural failure and functional failure (1). In brief, structural failure results in the inability of the pavement to sustain imposed loads while functional failure (for highways) results in passenger discomfort. The two types of failure are not necessarily related. In addition, the entire matter is clouded by valid questions of "degree."

Closely related to the problem of defining failure is the matter of differentiating between index properties which correlate well with ability to build and material parameters of the pavement system which characterize the response of the system to load. Because considerations of material parameters are still in their early development relative to considerations of index properties, investigators who attempt to evaluate tests (such as the AASHO Road Test) from a mechanistic standpoint must avail themselves of index properties and/or make grossly simplifying assumptions. One might expect, therefore, considerable data scatter and variations in results. At the present level of knowledge, poor results do not necessarily imply poor theory or inappropriate mechanisms. Poor results may well imply imperfect and/or incomplete knowledge of material parameters.

It is apparent from the preceding discussion that among the needs of the profession are clear, unambiguous definitions of performance and failure. Such definitions, relative to the system under consideration, may be embodied in the present serviceability concept as first reported by Carey and Irick (2). Many engineers have adopted the trend of present serviceability index (PSI) of a particular pavement section with increasing number of axle applications as a definition of performance of that section (3; 4, report 5). In addition, a

In [illegible] important performance is perhaps the are fundam[illegible] [illegible] failure. [illegible] two types of failure are recognized [illegible] and functional fail[illegible] (7). [illegible] of the movement to maintain [illegible] result in excessive [illegible]. The two [illegible] closely related. In addition, the [illegible] factors.

closely [illegible] is the [illegible] of differentiability, [illegible] ability to mild and material [illegible] which determine the response of the system [illegible]. Some of these parameters are still in their early [illegible] independent properties, investigators who [illegible] and test) from mechanical [illegible] properties. [illegible] grossly simplified [illegible] property characteristics, considerable data scatter [illegible] the present [illegible], or results [illegible] necessarily [illegible] not reason [illegible] imply [illegible] incomplete [illegible] transfer.

It is [illegible] for [illegible] needs [illegible] the profession [illegible] failure. Such failure, [illegible] in [illegible] ability [illegible] (7). [illegible] adequate [illegible] longevity [illegible] movement reaction with [illegible] as [illegible] performance of these [illegible] Figure 5). In addition, pavement whose PSI is 3.5 is generally conceded to be a "good" pavement while a pavement whose PSI is 1.5 is considered to be a "poor" pavement. "Failure," as such, still lacks a rigid definition. The PSI concept has at least produced a frame of reference and has been used throughout this report as the measure of performance.

It is not the purpose of this report to investigate the PSI concept; it should be noted, however, that the nature of the concept is essentially one of functional failure or functional performance. As a result, one cannot expect distinctive relationships, a priori, between the predictions of mechanistic theory (stresses, strains, displacements) and pavement performance or pavement "failure" as defined by some arbitrary value of PSI. Nevertheless, the research did disclose some discernable trends which are discussed subsequently.

In the course of the research, the connection between two links in a phenomenological chain was sought. The first link was considered to be an input of vehicles and ambient conditions on the highway. The second link, the output, was performance. It was hypothesized that the connecting mechanisms or transfer functions were stress and displacement. The input and output of a mechanistic approach is the same as the statistical study (4) but the statistical approach does not necessarily attempt to relate input and output through physical laws. In the mechanistic approach, on the other hand, it is assumed that the transfer functions can be obtained from governing laws. It is within this framework that the mechanistic approach introduces the concepts of stresses and displacements as measures of the transfer of boundary loadings and ambient conditions within the pavement body. It is reasoned that loads* cause stresses and displacements within the

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* "Load" here includes considerations of ambient effects.

pavement system which at least in theory, are determinable. Loads are empirically related to performance and performance, in turn, is a function of PSI. Performance (and therefore PSI) is thus related to stress and displacements. In sum, given a loading input, stresses and displacements within the pavement are determined and should relate to the overall performance, i.e., the PSI output, of the pavement system.

RESEARCH APPROACH

The general approach reported herein to the problem of extending the road test performance concepts consisted of the following three phases:

1. a detailed survey and review of literature
2. cataloging of existing theories and design procedures
3. checking where possible the reliability of theory in light of the results of the AASHO Road Test

Phase 1 - Surveying and Reviewing the Literature

The objective of this phase was to become familiar with those mechanistic models which might be useful in the prediction of pavement performance. To this end, a list of the literature was compiled. The list was comprised of approximately five hundred articles and papers. It should be noted that while the number of basic mechanistic models is relatively small, accounts of expanded theoretical analyses together with reports of empirical work on pavement problems and experimental studies of theory have resulted in an enormous volume of literature. In the face of the inevitable problem of selection, the literature survey was terminated when it was felt that the most pertinent references and mechanistic models had been considered.

Phase 2 - Cataloging Existing Theories and Design Procedures

The objective of this phase was to order and classify the information obtained in the first phase. This was accomplished by cataloging the literature. It was not considered necessary for purposes of this project to catalog all the literature. In addition, upon closer examination, not all the articles and papers listed were of interest.

Of primary concern was that the catalog format facilitate the rapid and easy identification of limitations (such as theoretical assumptions) of work reported

in the literature. If a general mechanistic theory of pavement performance is ever to be evolved, it is evident that the theory must necessarily contain few limitations as to its applicability under arbitrary combinations of loading, materials and ambient conditions. It is, then, of utmost importance that the profession be aware not only of what has been done in the area of pavement performance, but also aware of the limiting framework (such as assumptions relative to the nature of the materials and boundary conditions) of what has been done within this framework.

In order to identify limitations of work reported in the literature and to provide a basis for retrieval of information, a coding system was devised. The coding system, used with a standard bibliographical notation of author's name, publication, title, date, page numbers, etc., enable an article to be classified by means of symbols and symbol position on a standard five inch by eight inch index card. The symbols of the coding system (and certain bibliographic abbreviations) are explained in detail in Appendix C. An article was classified relative to five main categories which appeared on the cards as Roman Numerals I-V. Category VI was included on the cards for possible future use. The symbol appearing under I indicates the general nature of the article. Symbols under II give an indication of assumptions made relative to the properties of the materials involved. Symbols under III are related to the compositions of the materials. The number of layers considered can be determined by noting the number of symbols appearing under II and III. Symbols under V indicate what ambient effects were considered, if any. In addition, footnotes were used to amplify or explain important points.

It was anticipated that the coding system would not be universally applicable. Some literature was of the survey type; other articles were difficult to classify and were subjected to arbitrary classification. Nevertheless, it was felt that in the main, some degree of consistency in codification was attained

and that the system served its purpose. Appendix D contains the codified literature.

Phase 3 - Checking Where Possible the Reliability of Theory in Light of the AASHO Road Test

The objective of this phase was to determine, where possible, the reliability of mechanistic theories in predicting pavement performance. Data from the AASHO Road Test was analyzed.

It was assumed that performance could be determined by the trend of the present serviceability index with increasing number of axle applications. It was then hypothesized that theoretical stresses and/or deflections were functionally related to performance.

From the results of the first two phases of this project, it was apparent that all existing theories embodied some concept of material parameters, i.e., numbers such as modulus of elasticity or Poisson's ratio which in some way characterize the response of materials to load as opposed to index properties, such as Atterberg limits, grain size distribution and strength tests, etc., which correlate well only when used with particular analytical procedures. In general linear elastic theory, for example, twenty-one independent constants relate stress and strain at a point. Considerations of homogeneity (all points identical) and isotropy (no change with direction) reduce the number of constants within a body to two. In viscoelastic theory, the behaviour of a material is characterized by time-independent elements and viscous elements. Material parameters are expressed in terms of equivalent spring and dashpot constants. In the theory of critical or limiting equilibrium, "strength" parameters are considered to typify the material. These strength parameters commonly take the form of an angle of internal friction ($\tan^{-1}$ of the Mohr envelope) and a cohesion (intercept of the Mohr envelope on the

shear axis). It should be noted that all material parameters are in fact parameters of mathematical models which attempt to simulate the action of real materials. In some materials (notably metals) the simulation has been very successful. In other materials, the simulation has been less successful due, at least in part, to the lack of definition of meaningful parameters. In addition, if it is assumed that material parameters can characterize a material, other questions arise immediately; for example:

(1) What parameter(s) should be measured?

(2) How may the parameter(s) be determined? - as a corollary, what similitude exists between a laboratory specimen and the prototype?

(3) Do the parameters vary with time and ambient conditions? If so, how?

These questions are by no means new but in the course of conducting the research for this project, it became painfully apparent that they still remain unanswered. The state of the art is so confused that even when it is agreed to measure a certain parameter, differences of opinion arise on one hand as to how the parameter is to be measured and on the other hand, in interpreting the resulting values. In addition, few attempts have been made to assess time variations of parameters.

An indication of differences that exist when attempts are made to measure parameters of the same materials is apparent from even a cursory study of the results of the cooperative testing program (5). Considering, for example, the embankment soil, values* of ϕ, angle of internal friction, ranged from 23° to 0°

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* Values of ϕ and c were either reported directly by agencies conducting the tests or were determined by Shook and Fang from data submitted by the agencies.

while values of c, cohesion, ranged from 35 psi to 2 psi. Variations in ϕ and c on the same order were obtained for the subbase and base course materials. Difficulties in determining other material parameters have been reported elsewhere (6).

In summary, it was felt that reliable information on parameters of materials used in the AASHO Road Test were either lacking or so inconsistent as to render rational choice impossible. It was apparent that any subsequent analyses would of necessity be of a non-dimensional form or of a form which required no distinct material parameters.

Because of the problems cited above and because multi-layer theory seemed to offer no particular advantages from the standpoint of accuracy of prediction (6), it was decided to analyze* performance on the basis of the Boussinesq equations** for stresses and deflections occurring under a uniformly loaded circular area. The analysis was thus based on a theory which presupposes a homogeneous, isotropic, elastic system. Extensive use was made of tabular values (10) to facilitate solutions of the equations.

The Boussinesq equations were derived for a static load. Some question might therefore arise concerning the applicability of the Boussinesq relationships to a situation where loads were dynamically applied as in the AASHO Road Test. It should be noted that stresses and displacements seem to be related to vehicular

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* Only data from selected flexible pavement sections at the AASHO Road Test were analyzed herein. In order to assess mechanistically the response of rigid pavements, it is necessary to have some indication of pavement support conditions (7, 8, 9). In view of the lack of such information, rigid pavements at the AASHO Road Test were excluded from the analysis.

** In subsequent work, references to Boussinesq stresses and deflections will imply results of the Boussinesq equations (unless otherwise noted) for stresses and deflections for homogeneous, isotropic, elastic systems.

speed in a reasonably consistent manner (11, 12) so that one might assume that the actual stresses and displacements caused by the test vehicles (whose speed was a constant 35 mph) at Ottawa were related to the Boussinesq stresses and displacements by a constant. Such an assumption was made in the analysis reported herein. Because the purpose of the analysis was simply to investigate the possibility of obtaining functional relationships between input and output, it was felt that the assumption was justified. Another question concerning the applicability of the Boussinesq relationships might arise in regard to the assumption of a homogeneous, isotropic, elastic pavement system. The authors feel that this assumption is no more restrictive for purposes of analysis than is the inherent assumption in multi-layer theories concerning the transmission of shear stress or displacement across layer boundaries.

As noted above, the purpose of the analysis was to investigate the possibility of obtaining functional relationships between input (number of axle applications) and output (performance). To this end, stresses and normalized deflections* were computed for single axle loads of 6,000, 18,000 and 30,000 pounds. Number of axle applications to two levels of serviceability (3.5 and 1.5) were considered. The data is contained in tabular form in Appendix B.

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* The product of vertical deflection at the top of embankment and modulus of elasticity.

FINDINGS

General

The findings reported herein were obtained from analyses of numerous graphs on which number of axle applications was plotted as a function of theoretical stresses, combinations of stresses, and normalized deflections. As an aid to comprehension, the graphs were plotted on several types of coordinate paper - arithmetic, semi-logarithmic and double logarithmic. Most of the graphs in this report are of the latter type.

Plots were made of actual number of axle applications, N_u, versus stress or normalized deflection for two levels (3.5 and 1.5) of serviceability; the plots were examined and trends (if any) noted. A typical plot appears in Figure 20.* In an attempt to consider ambient effects, additional plots were made of weighted** number of axle applications, N_w, versus stress and normalized deflection; some improvements in trends were noticed - see Figures 2-10; 12-17. An unsuccessful attempt was made to extend the concept of a sinusoidal variation of creep speed deflections with time (13) to a similar variation of modulus of elasticity with time. No further attempt was made to consider the time dependency of material parameters.

In addition to the plots described above, a plot of N_w versus vertical stress at the subbase - embankment interface was made which employed three-layer theory and data which appeared elsewhere (14). This plot appears in Figure 21. It was decided that three-layer theory represented no significant improvement over Boussinesq theory and hence the three-layer theory was excluded from further consideration.

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* All figures are located in Appendix A.

** AASHO procedure.

In summary, the graphs may be placed into three categories, the first of which consisted of N_w plotted against σ_z, the Boussinesq vertical normal stress. It should be noted that the concept of stress as a measure of the transmission of forces through a medium was considered basic to a mechanistic interpretation of Road Test data.

The second category of graphs included N_w plotted against Boussinesq shearing stress, τ_{rz}, or some combination of normal stress and shearing stress. This second set of data was analyzed with the hope that a more definitive trend could be established than that which existed between N_w and σ_z.

Some of the computations involved assumptions as to the value of μ, Poisson's ratio. Different values (0, 0.3, 0.5) of μ were tried; however, variations in μ had the effect of merely shifting the plots horizontally in a rigid manner with no decrease in scatter of the data. Because the choice of 0.5 for μ had some computational advantages, that value was assumed for subsequent analyses.

The third category of graphs involved N_w plotted against W_zE, normalized Boussinesq deflection. It was thought that deflections might be used as a predictor of N_w, particularly in view of the following statement:

"The performance of the flexible sections was predicted with essentially the same precision from load-deflection data as from load-design information" (4, report 5).

It should be noted that in Figures 2-10 and 18-23, all stresses and normalized deflections were computed beneath the center of a dual tire assembly at the subbase-subgrade interface (top of embankment). The subscript "1" implies calculations beneath the center of a dual tire assembly; thus; σ_{z_1} denotes the Boussinesq vertical normal stress calculated at the point shown in Figure 1-A. In Figures 12-17, the computations refer to a point beneath the center of one tire at the

top of the embankment. The subscript "2" implies calculations beneath the center of one tire; thus; $W_{z_2}E$ denotes normalized Boussinesq vertical deflection at the point shown in Figure 1-B.

Major Findings

Figures 2-10 and 12-17 represent the major findings of this phase of this project. Several important facts emerged from detailed study of these figures; namely:

1. The mechanisms of vertical stress, shear stress, and vertical deflection are not the primary controlling factors in thin, flexible pavements subjected to light loads - see Figures 2, 5, 8, 12 and 15. A major cause of rapid failure of such pavements is undoubtedly adverse ambient conditions. At the present time, the effects of ambient conditions are not amenable to analysis from a mechanistic standpoint; that is, there is no way of assessing the number of axle applications under one condition which corresponds to a number of axle applications under another condition. It should be noted, however, that the "seasonal weighting function" (4, report 5) used in the determination of N_w, was based on mechanistic considerations - relative deflections - and proved useful in this project in making relationships between axle applications and stresses or displacements more discernible especially with the heavier loads and thicker pavements. In the case of the 6,000 lb. single axle load and the thinner pavements, the seasonal weighting function was of little value; perhaps other considerations, such as punching shear, are more critical than deflections with such pavements. Here again, insufficient and inconclusive information prohibited further and perhaps more meaningful analyses.

2. The remaining figures in this group indicated trends which are characterized by the following relationship within the range of practical interest:

$$N_w = UF_B^V \qquad (1)$$

where:

N_w = weighted number of axle applications

F_B = Boussinesq vertical normal stress, shear stress, or normalized deflection

U,V = parameters

The following observations appear warranted:

a) The general slopes of the trends (the parameter V on double logarithmic paper) are of the anticipated sign, i.e., negative, so that the higher the value of F_B, the lower N_w at a given serviceability level. This observation is not profound; nevertheless, it is of interest to note that the trends conform to physical reality.

b) The shapes of the trends are insensitive to the horizontal location of F_B. The abscissas of Figures 3 and 4 depict σ_z at the top of embankment and midway between the tires of a dual set; Figures 13 and 14 portray the same information but σ_z was computed beneath the center of one tire of a dual set. The shapes of the trends in both sets of figures are practically the same; similar statements apply to Figures 9 and 10 when compared with Figures 16 and 17. These phenomena are manifestations of the well known fact that at a sufficient distance from the point of loading, the effects of boundary loads between tires are essentially the same as those under one tire.

c) In general, there was little horizontal spread between serviceability levels of 3.5 and 1.5; apparently, the serviceability index is quite sensitive to changes in a given F_B, that is, for a given N_w, a relatively small change in F_B results in a change in PSI from 3.5 (good) to 1.5 (poor).

d) The data are reasonably reproducible at least insofar as similar stresses or displacements at a given level in the pavement resulted in about

the same value of N_w irrespective of the total load at the surface of the pavement.

e) The slope V is a function of F_B, i.e. V varies as the abscissa changes from σ_z to τ_{rz} to W_zE and, in the strict sense, V is also a function of the serviceability index; however, at the present time for all practical purposes, V could be considered independent of the serviceability index.

f) The intercept U is a function of F_B and of the serviceability index. As a given F_B approaches zero, N_w becomes very large. If U is assumed to approach infinity as F_B approaches zero, the form of equation (1) would change. Within the range of practical interest (large but finite N_w) equation (1) appears adequate and offers some advantages from the standpoint of extrapolation of data.

g) In Figures 12-17, a point was shown whose ordinate is unity (0.001×10^3). These points were determined by assuming the embankment material alone could withstand only one axle application before its serviceability index fell to some undetermined but low value. The abscissa was considered to be the maximum value of a given F_B that could occur immediately beneath the tire. In the case of vertical normal stress and normalized vertical deflection, the maximum value of F_B occurred beneath the center of one tire. After plotting these points, it was observed that in general they were essentially collinear with those points three decades above in the main portion of the graph. In addition, little deviations were introduced in the trends if the low value of serviceability was assumed to occur after, say, ten axle applications instead of one application. It was felt that this observation provided a somewhat firmer basis for any extrapolation of the trends and helped greatly to affirm the basic hypothesis of this project.

Minor Findings

1. Two figures were included herein to illustrate the trends which resulted when N_w was plotted against vertical normal stress on arithmetic paper (Figure 18) and against shear stress on semi-logarithmic paper (Figure 19) for the 18,000 lb. single axle load.

2. Figure 20 portrays N_u, unweighted number of axle applications, plotted against σ_z on arithmetic paper for the 18,000 lb. single axle load. A comparison of this figure with Figure 18 illustrates the advantage of using N_w as the ordinate rather than N_u.

3. Figure 21 illustrates the relationship between N_w and σ_z computed on the basis of the three-layer theory of Peattie and Jones (15, 16). A comparison of Figures 21 and 13 revealed no particular advantage resulted from the use of the more sophisticated but not necessarily more correct three-layer theory. In a strict sense, the figures are not comparable for the results shown in Figure 13 were obtained on the assumption that the principle of superposition was valid and hence the effects of the dual tire loading were additive while the results shown in Figure 21 were obtained by considering the 9,000 lb. wheel load to be distributed over one circular area.

4. Figures 22 and 23 represent attempts to obtain a more definitive relationship between N_w and the results of the Boussinesq equations. It was felt that while the plots did portray some trends, they were no more pronounced than those shown on previous plots; hence, no further efforts were made to analyze the relationships.

CONCLUSIONS

In view of the findings of this research, the following conclusions appear warranted:

1. Theoretical stresses and displacements are functionally related to performance where performance is defined as the trend of PSI with increasing axle applications.

2. Material parameters - their definition, determination and change with time and ambient conditions - are the "missing links" in the problem of extending AASHO Road Test results to other locations where ambient conditions, loading patterns and construction materials differ from those at Ottawa.

In regard to the first conclusion, it should be noted that the precise forms of the functional relationships between stresses, displacements and performance remain undetermined. This is due, at least in part, to the large amount of scatter exhibited by the data. Possible causes for the observed scatter of data are as follows:

1. The present serviceability index is essentially a subjective concept; in addition, the index proved to be quite sensitive to stresses and deflections.

2. Seasonal and diurnal changes had a marked but quantitatively unknown effect on AASHO Road Test pavements. This is readily evidenced by the failures associated with the spring thaw periods.

3. Some data on number of axle applications to any given level of serviceability were inconsistent as evidenced by pronounced dissimilar behavior of some replicate pavement sections in the AASHO test.

4. Some pavement sections in the AASHO test withstood the entire testing program; hence, complete information on the performance of those sections was not available.

The essence of the second conclusion is not new; in fact, the conclusion is simply a comment on the state of the art at the present time. The conclusion merely states, in a manner directed to a particular problem, what is at least implicit in much of the literature. The second conclusion is most important, however, especially in light of the first for the first conclusion has indicated the existence of a direct relationship between mechanistic theory and performance at the one location while the second conclusion indicates the problems to be solved before information obtained at Ottawa can be transferred elsewhere.

SUGGESTED RESEARCH

In order to extend AASHO Road Test results on **any** rational basis, the following additional research is needed:

1. Extensive and definitive work on material parameters, especially with regard to changes in parameters induced by time and variations in ambient conditions.

2. Experimental work to determine the real nature of stress and/or displacement transfer across multi-layered system boundaries.

3. Experimental work to determine the support conditions of loaded pavements. That pavements are often unsupported over large portions of their areas is well established; rational analysis requires a comprehensive knowledge of the manner and form of pavement support when the pavement is loaded.

4. Experimental and theoretical work in which vehicle motion is considered in conjunction with properties of materials under dynamic loading conditions.

5. Experimental work on the effects of controlled, mixed traffic on performance; this might be accomplished by means of satellite road tests. The traffic at the AASHO Road Test was essentially homogeneous in nature in any given lane.

ACKNOWLEDGMENTS

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M. E. Harr, Professor of Soil Mechanics, Purdue University, was in over-all charge of the project; W. J. Head, Instructor in Civil Engineering, Purdue University, was concerned with the literature search and with data analysis.

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APPENDIX A

FIGURES

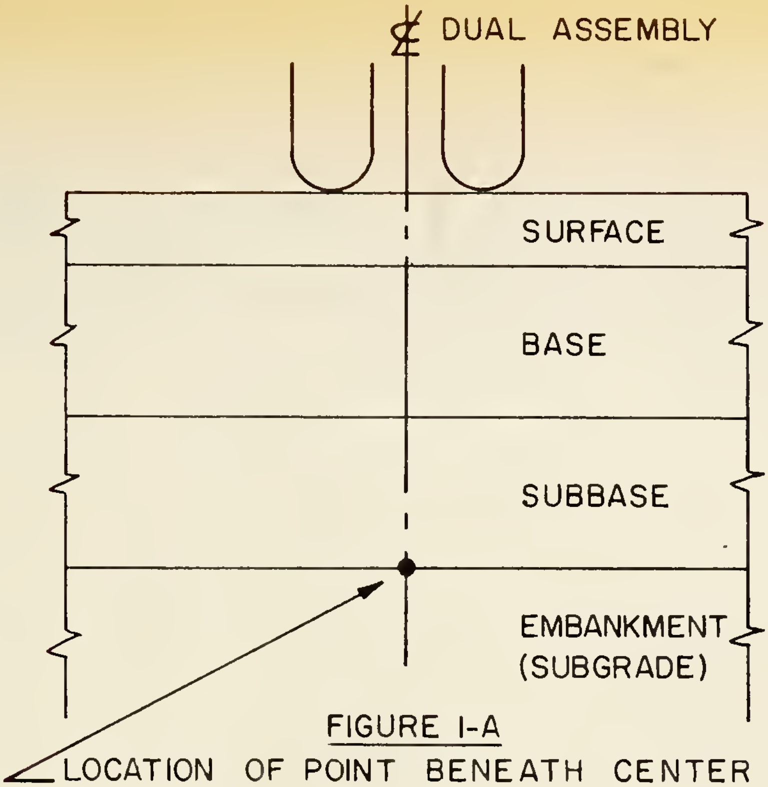


FIGURE 1-A

LOCATION OF POINT BENEATH CENTER LINE OF DUALS

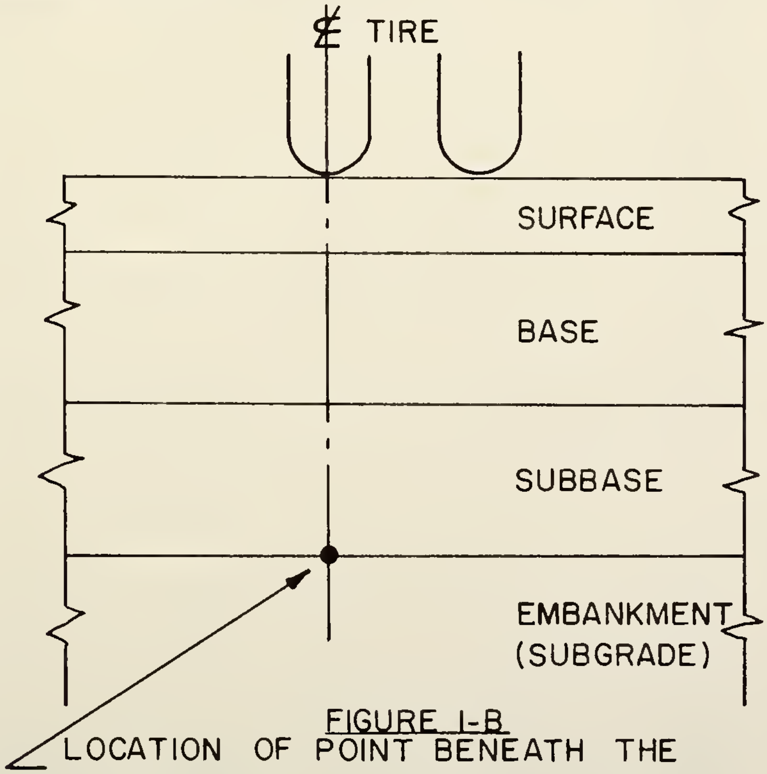


FIGURE 1-B

LOCATION OF POINT BENEATH THE CENTER OF A TIRE

FIGURE 1. POINTS IN THE PAVEMENT AT WHICH STRESSES AND DEFLECTIONS WERE COMPUTED

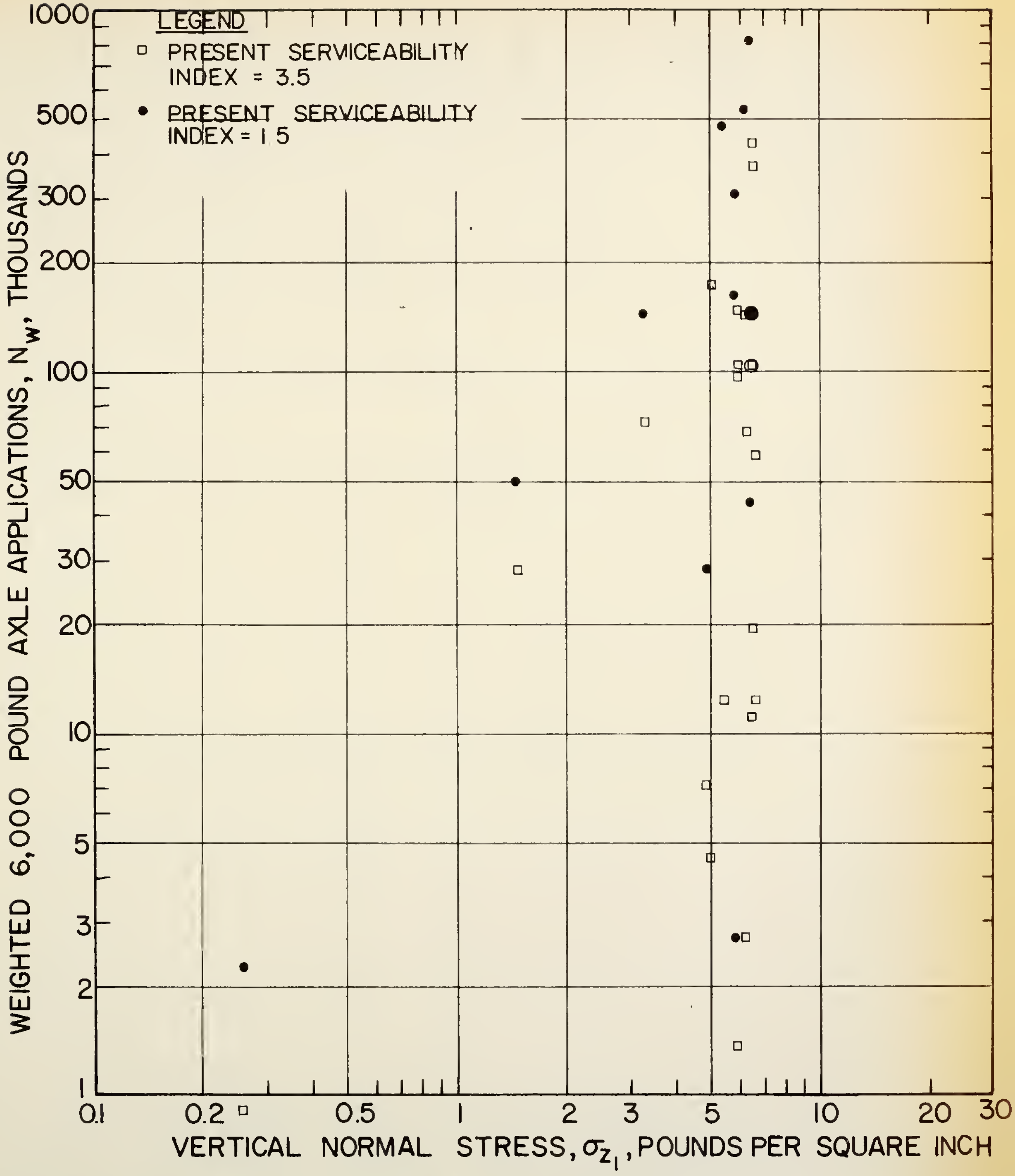


FIGURE 2. WEIGHTED NUMBER OF 6,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS

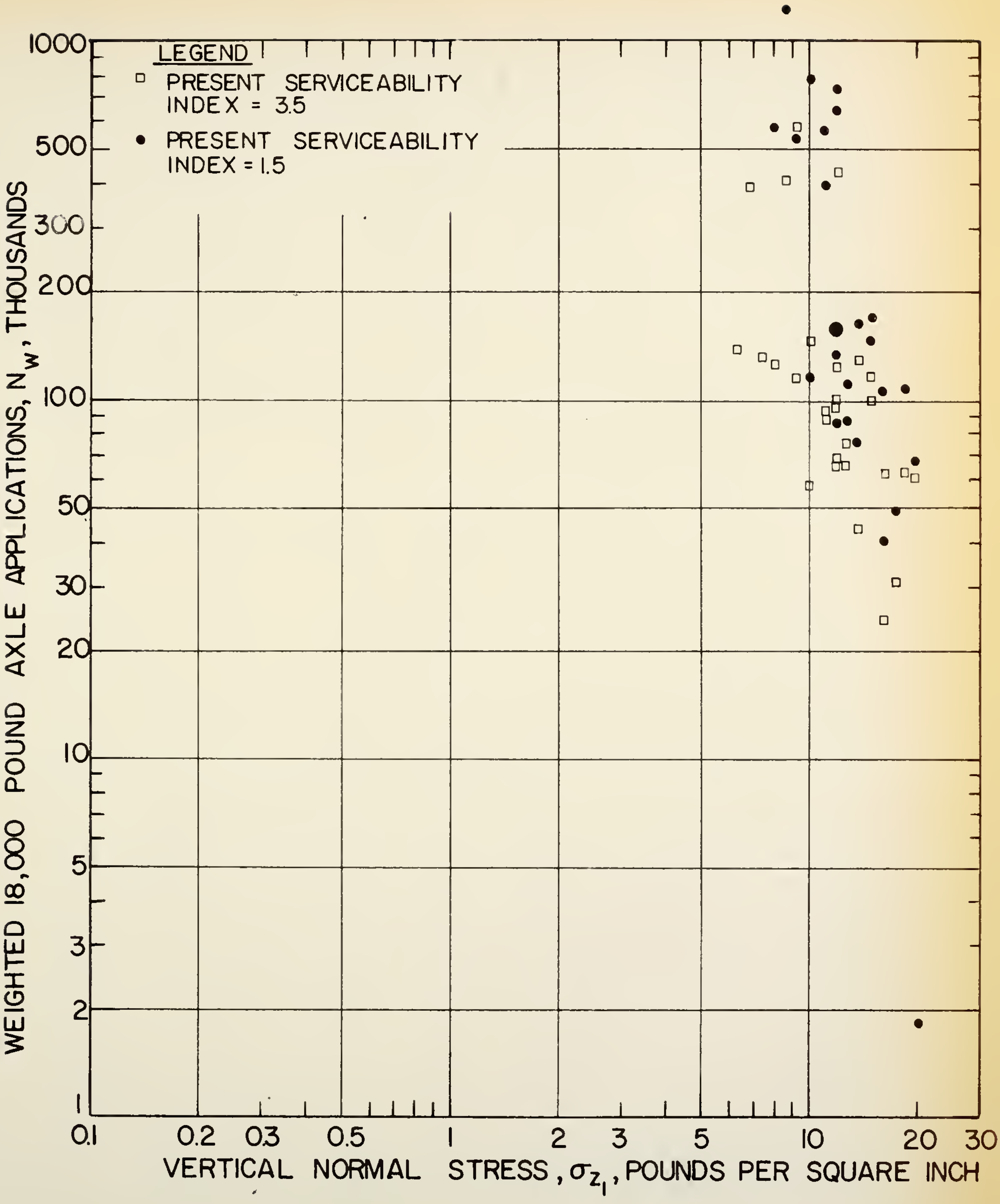


FIGURE 3. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS

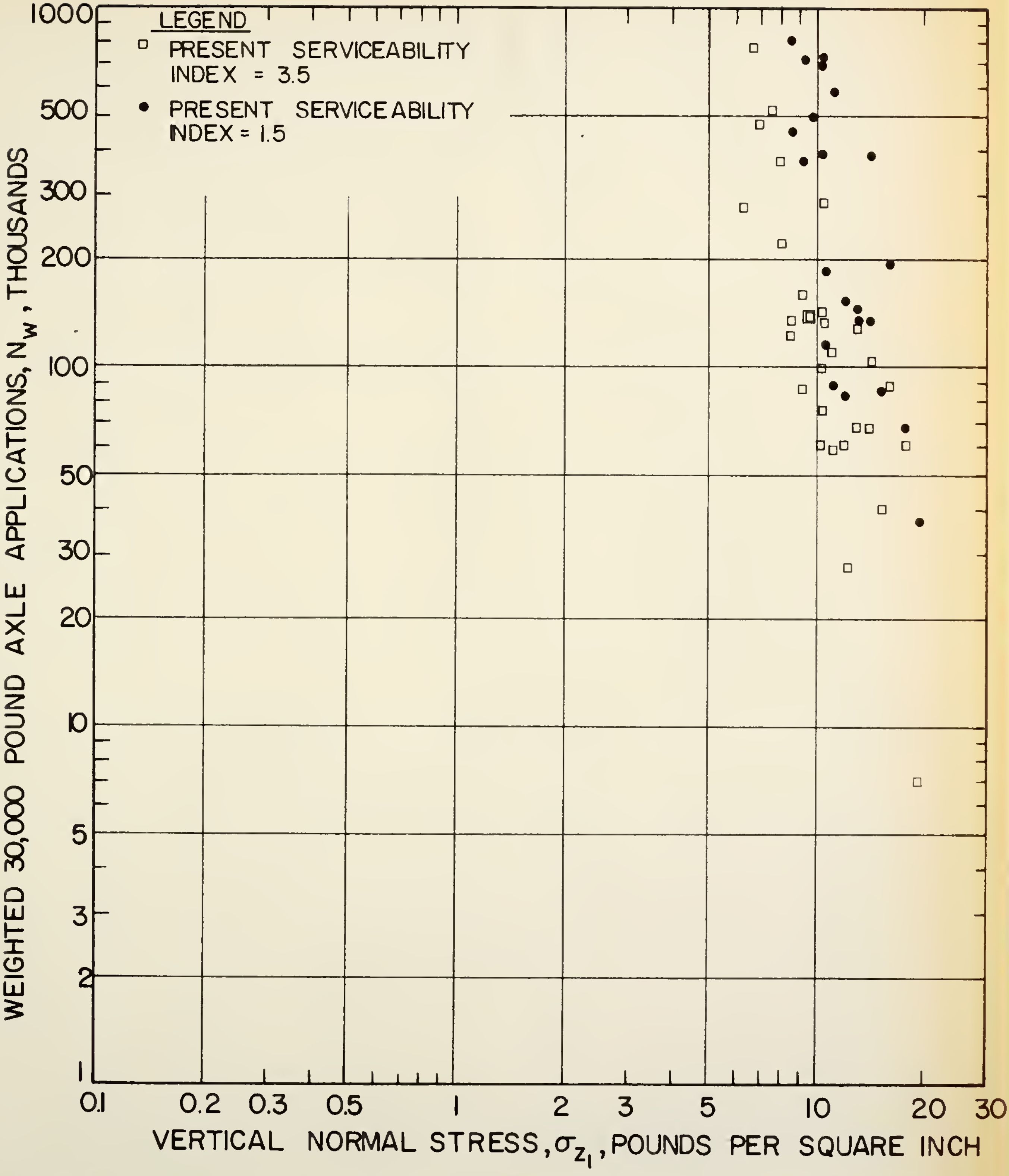


FIGURE 4. WEIGHTED NUMBER OF 30,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS

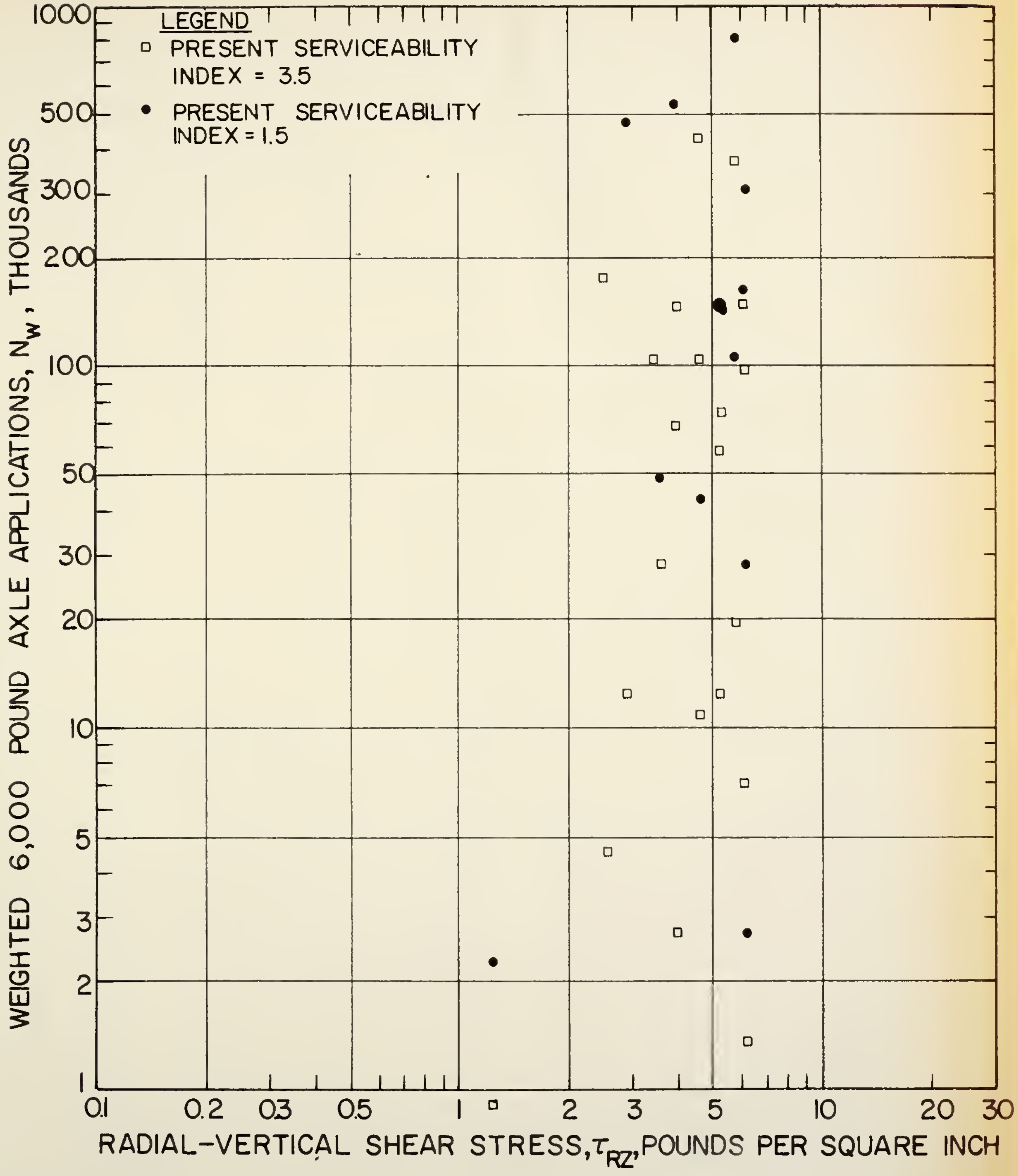


FIGURE 5. WEIGHTED NUMBER OF 6,000 POUND SINGLE AXLE APPLICATIONS VS RADIAL-VERTICAL SHEAR STRESS

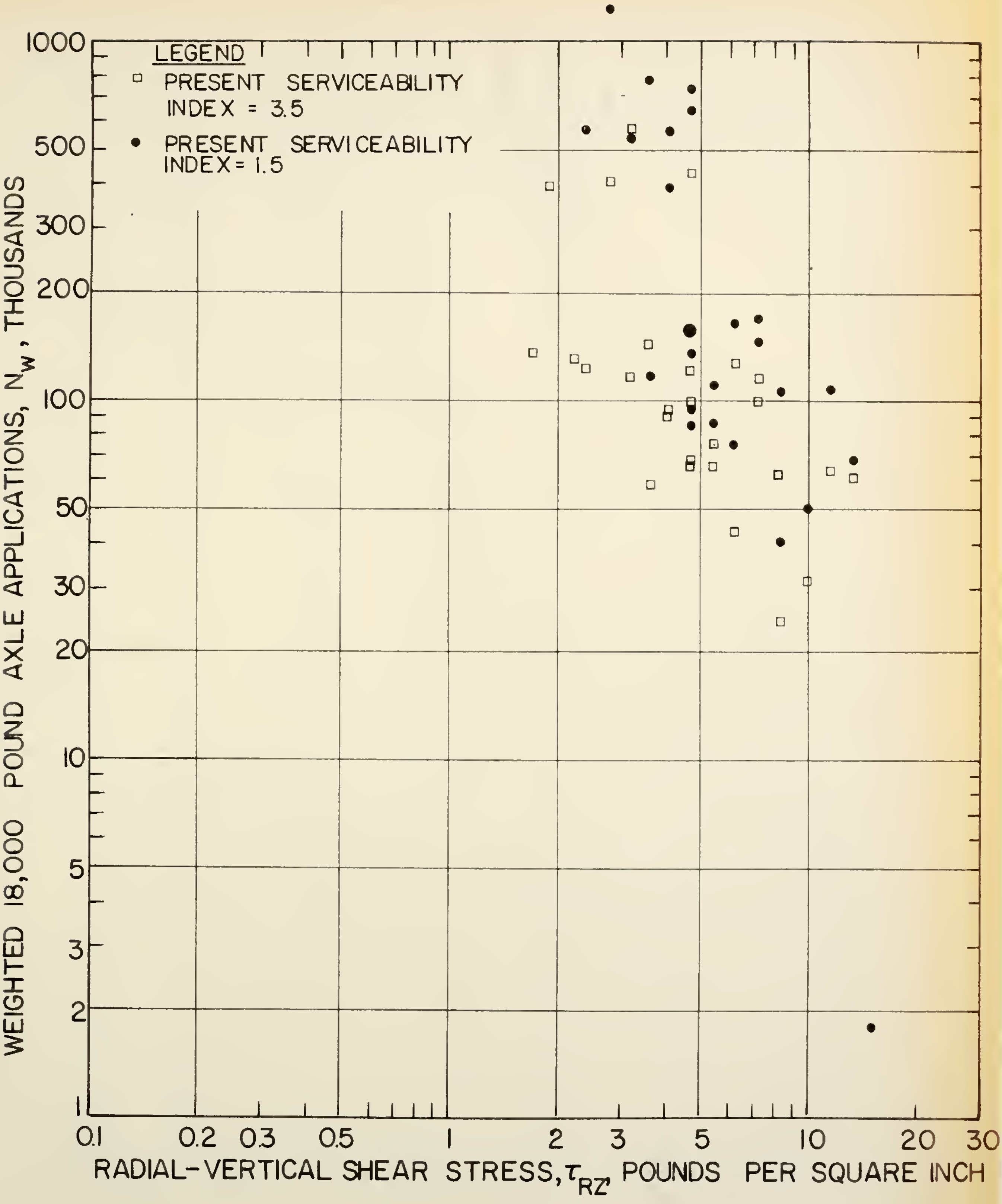


FIGURE 6. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS RADIAL-VERTICAL SHEAR STRESS

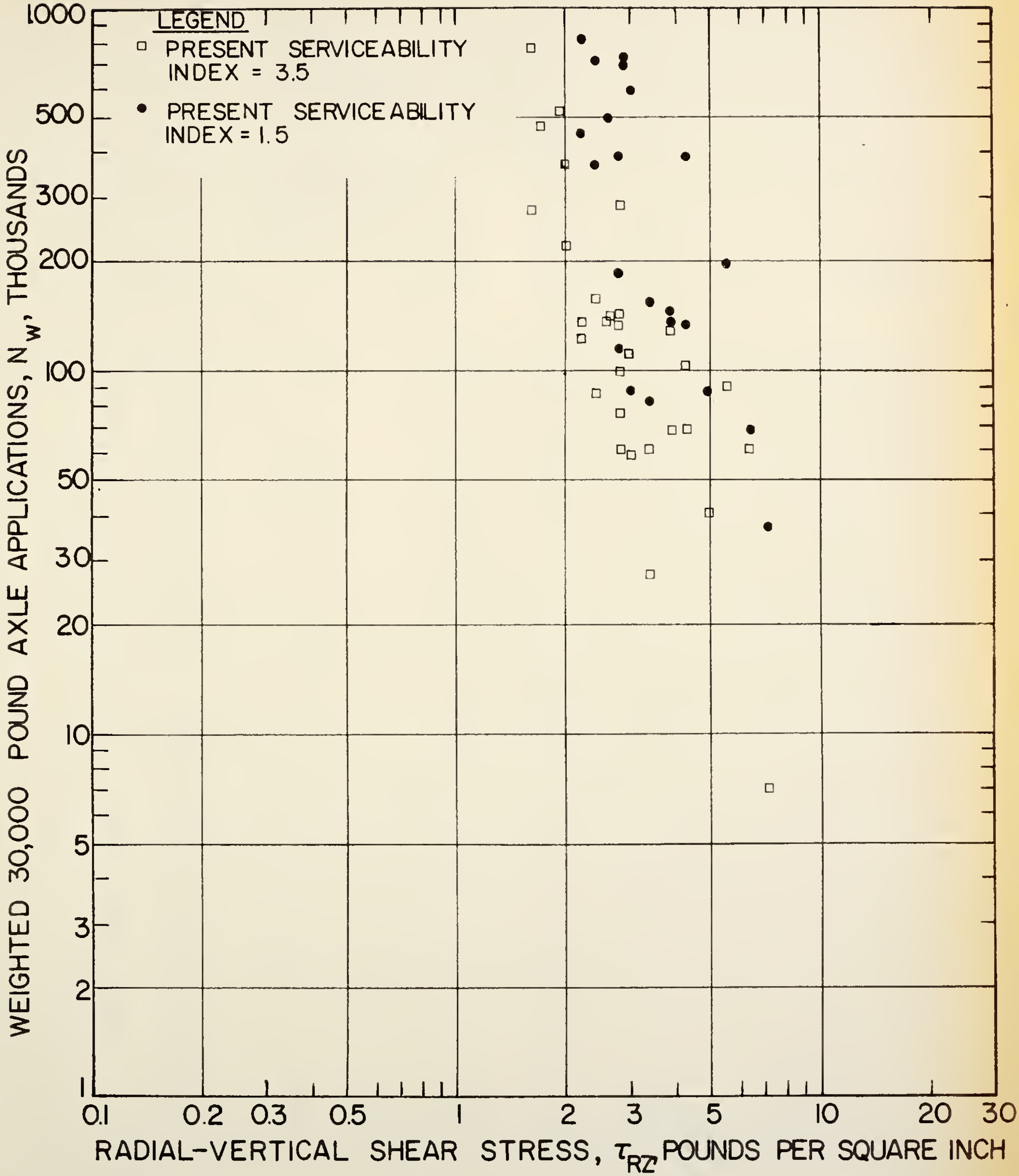


FIGURE 7. WEIGHTED NUMBER OF 30,000 POUND SINGLE AXLE APPLICATIONS VS RADIAL-VERTICAL SHEAR STRESS

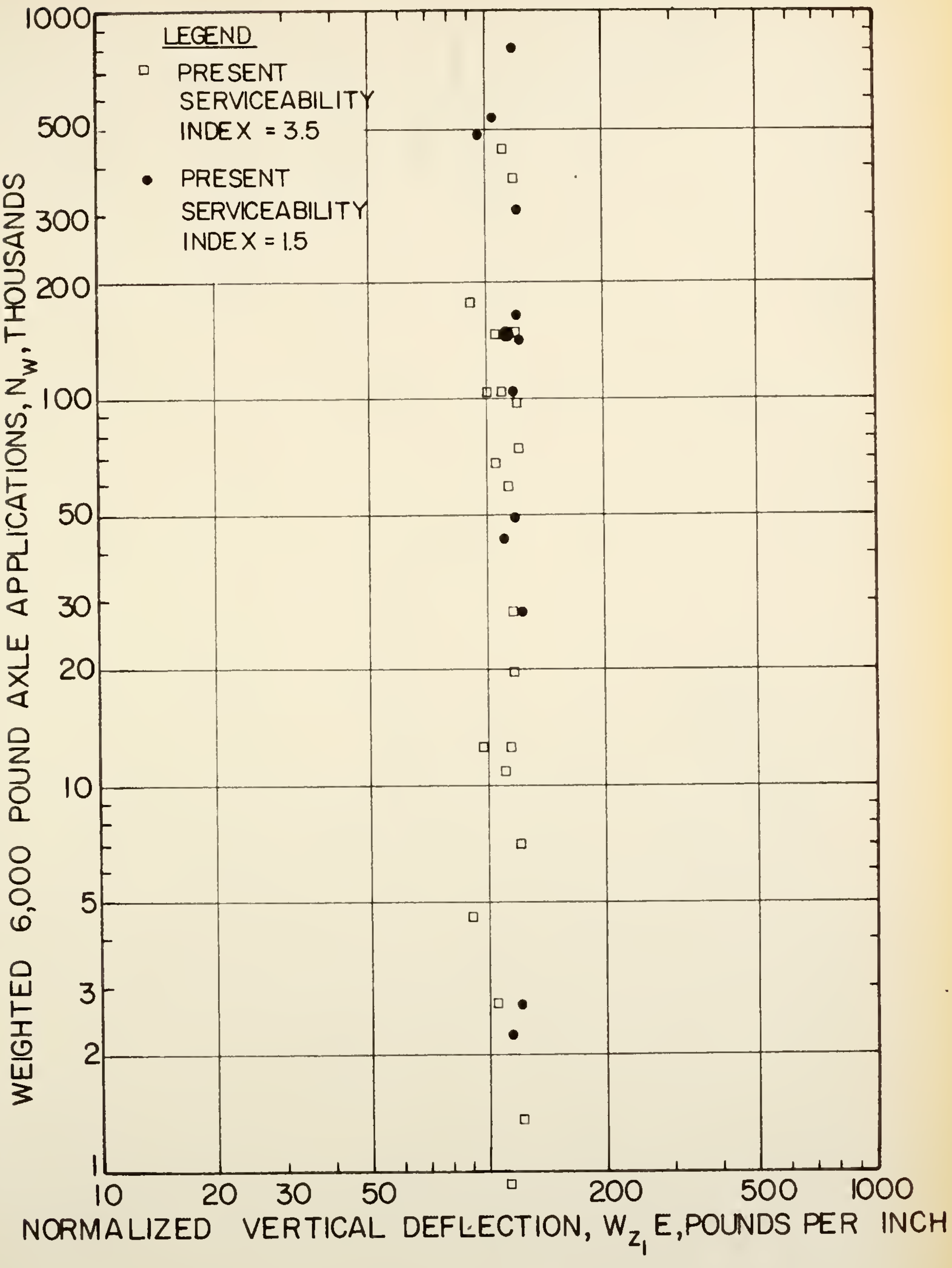


FIGURE 8. WEIGHTED NUMBER OF 6,000 POUND SINGLE AXLE APPLICATIONS VS NORMALIZED VERTICAL DEFLECTION

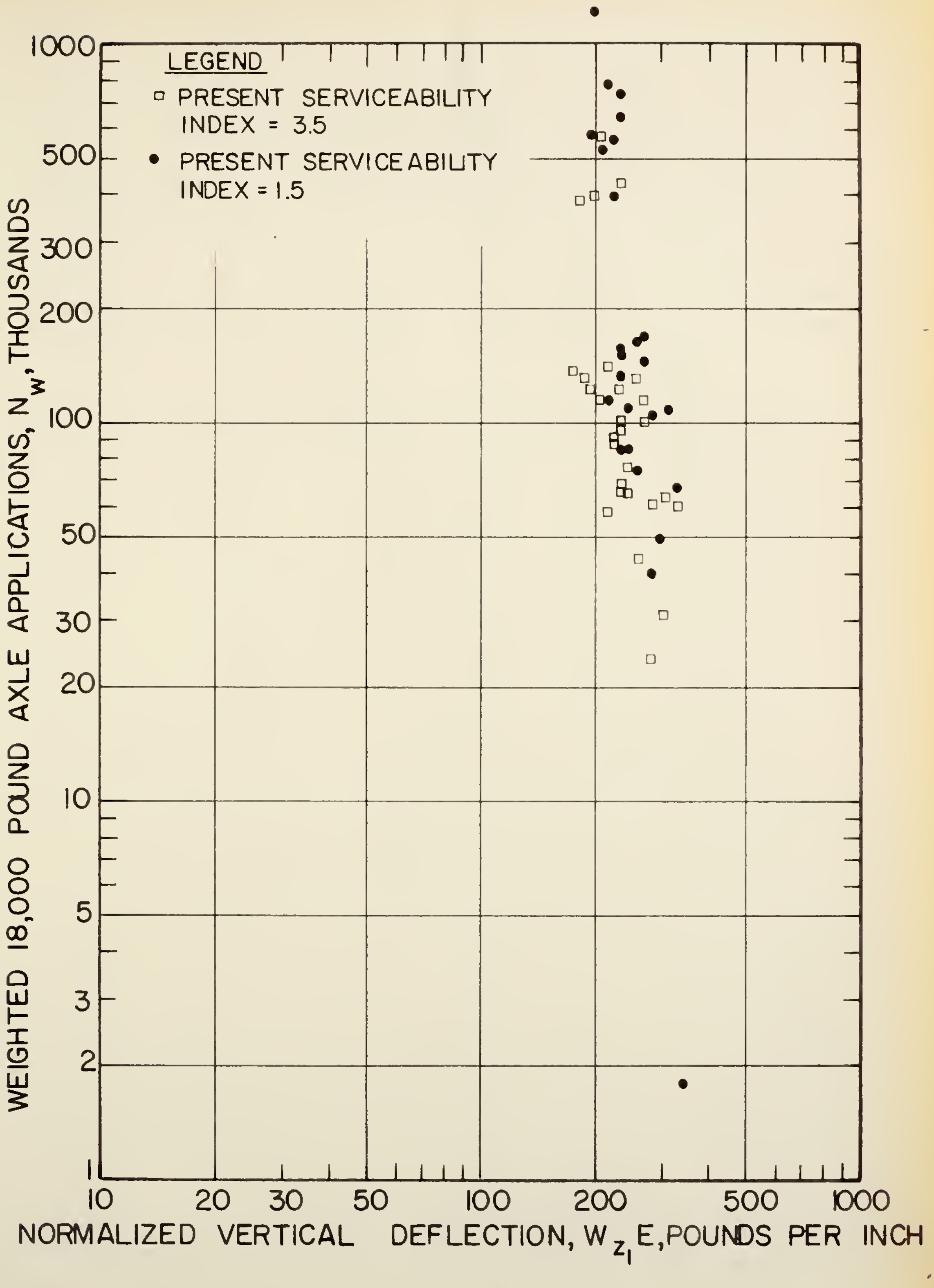


FIGURE 9. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS NORMALIZED VERTICAL DEFLECTION

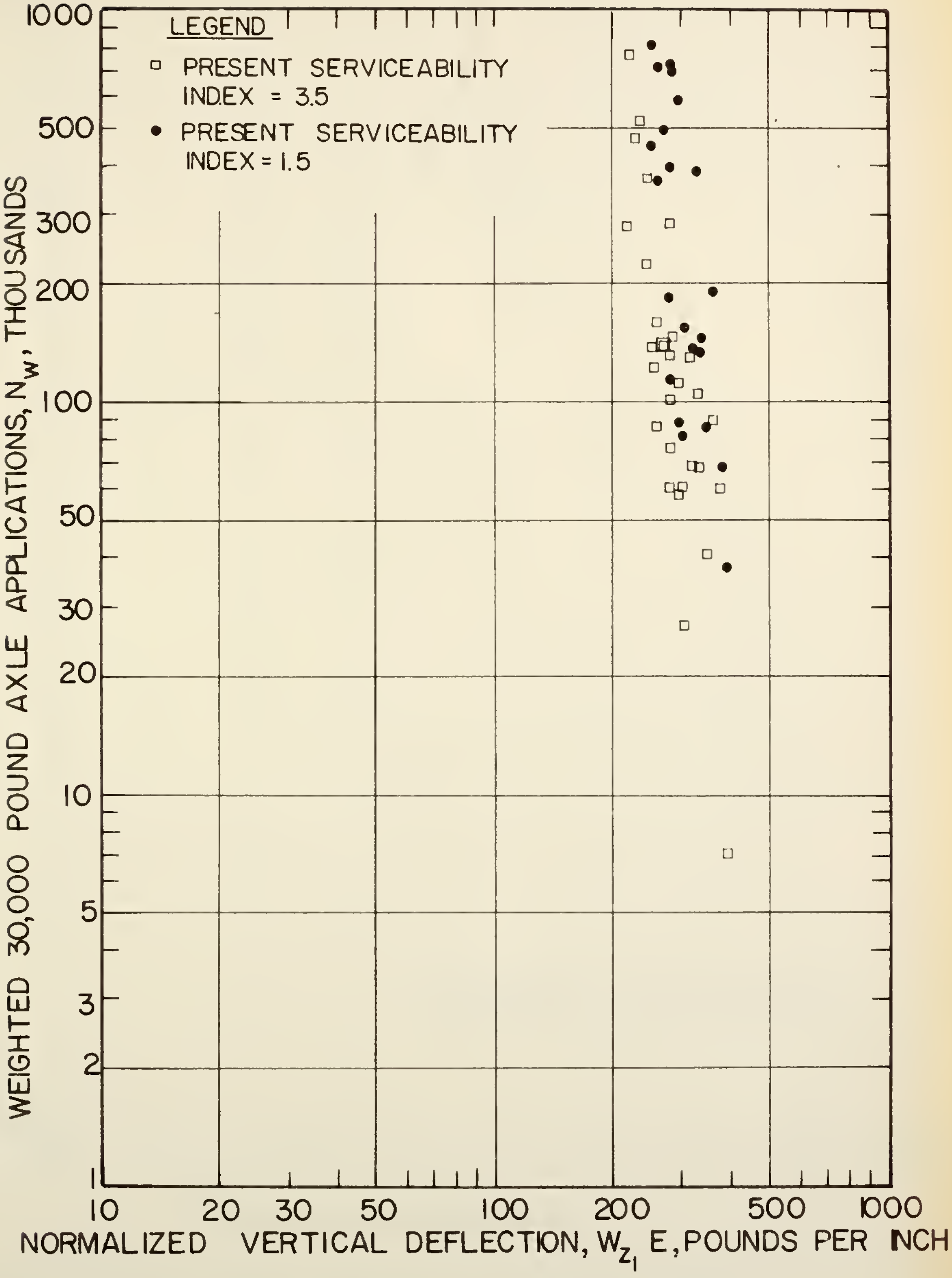


FIGURE 10. WEIGHTED NUMBER OF 30,000 POUND SINGLE AXLE APPLICATIONS VS NORMALIZED VERTICAL DEFLECTION

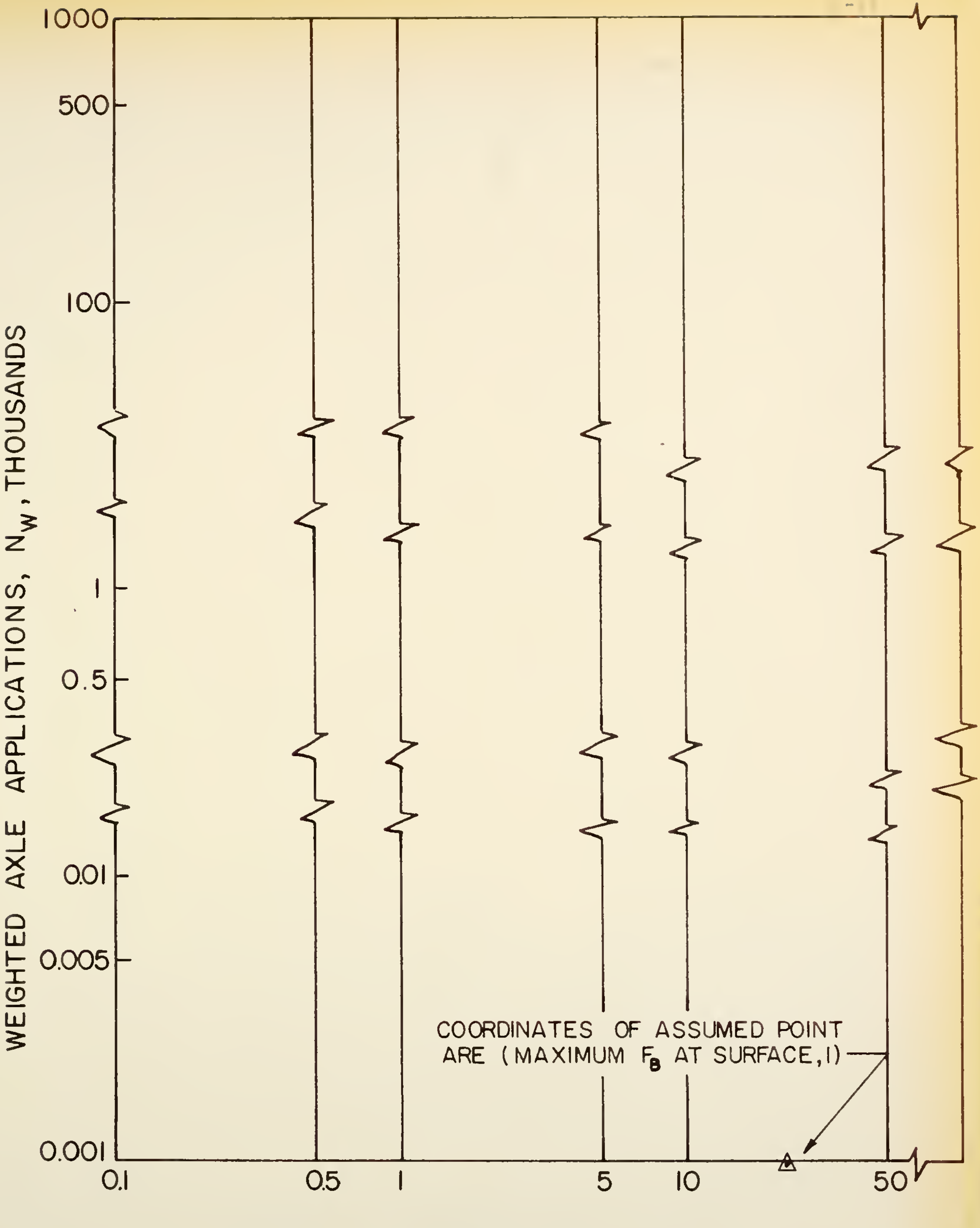


FIGURE 11. SCHEMATIC DIAGRAM SHOWING RELATIVE POSITION OF ASSUMED POINT

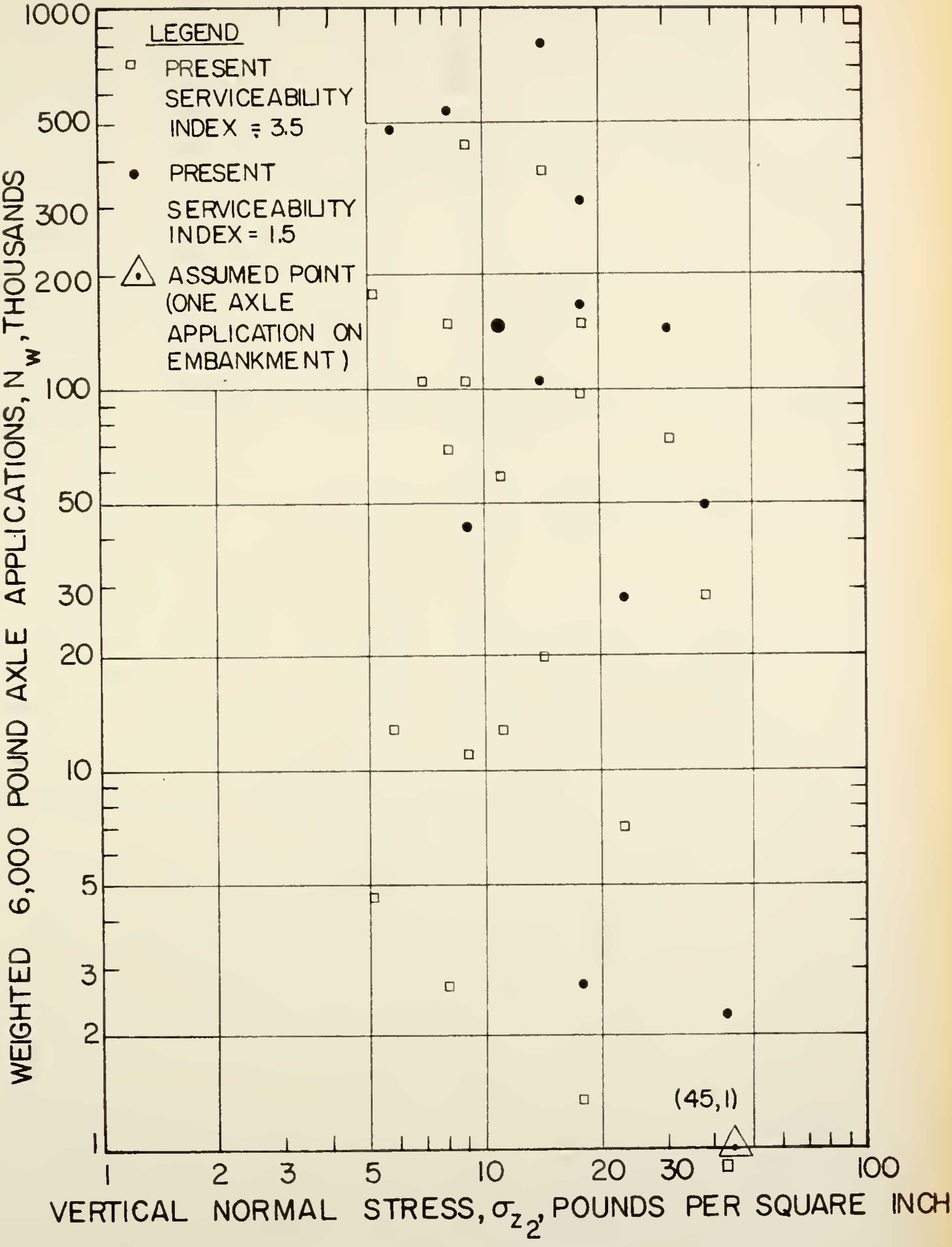


FIGURE 12. WEIGHTED NUMBER OF 6,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS

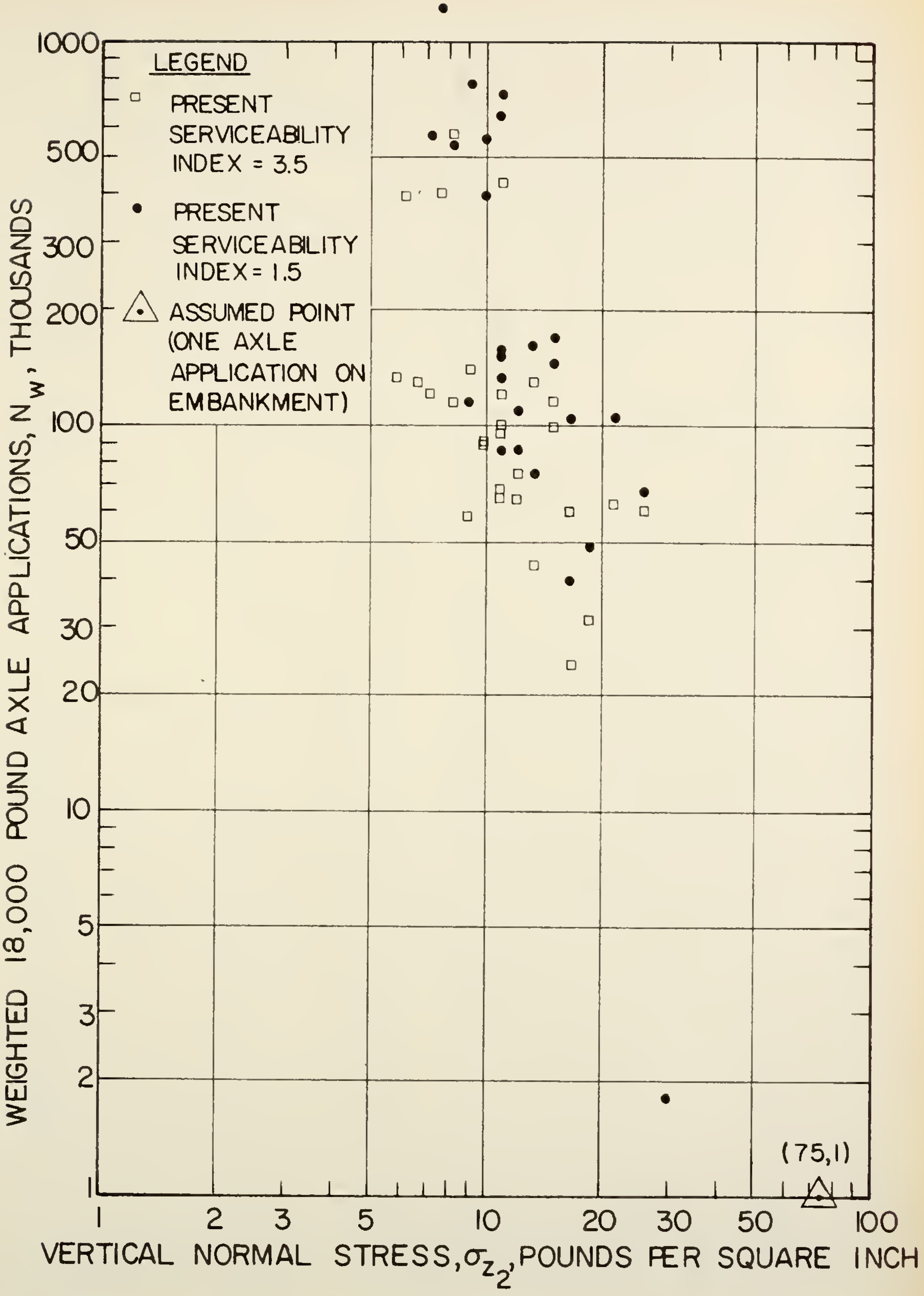


FIGURE 13. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS

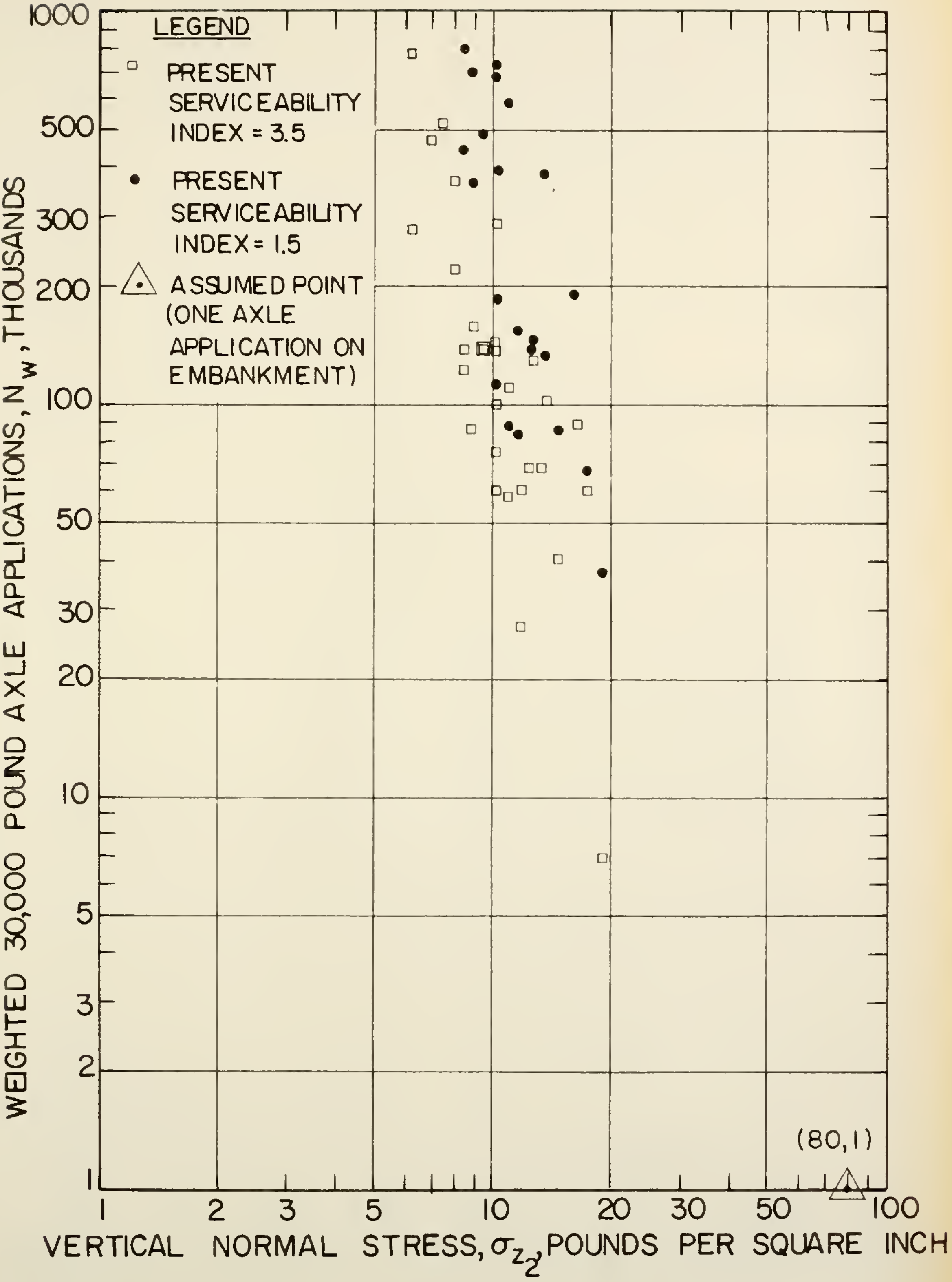


FIGURE 14. WEIGHTED NUMBER OF 30,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS

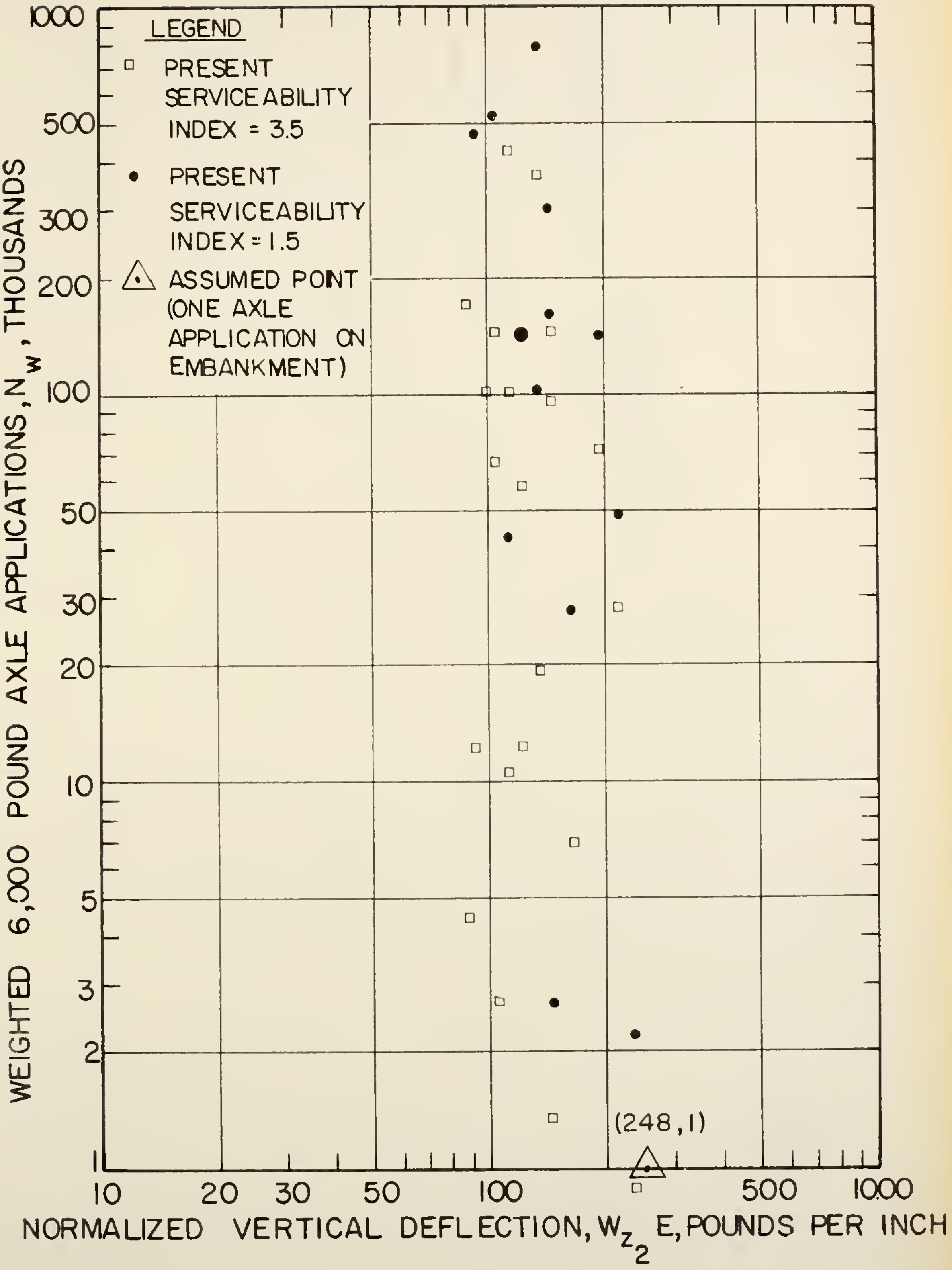


FIGURE 15. WEIGHTED NUMBER OF 6,000 POUND SINGLE AXLE APPLICATIONS VS NORMALIZED VERTICAL DEFLECTION

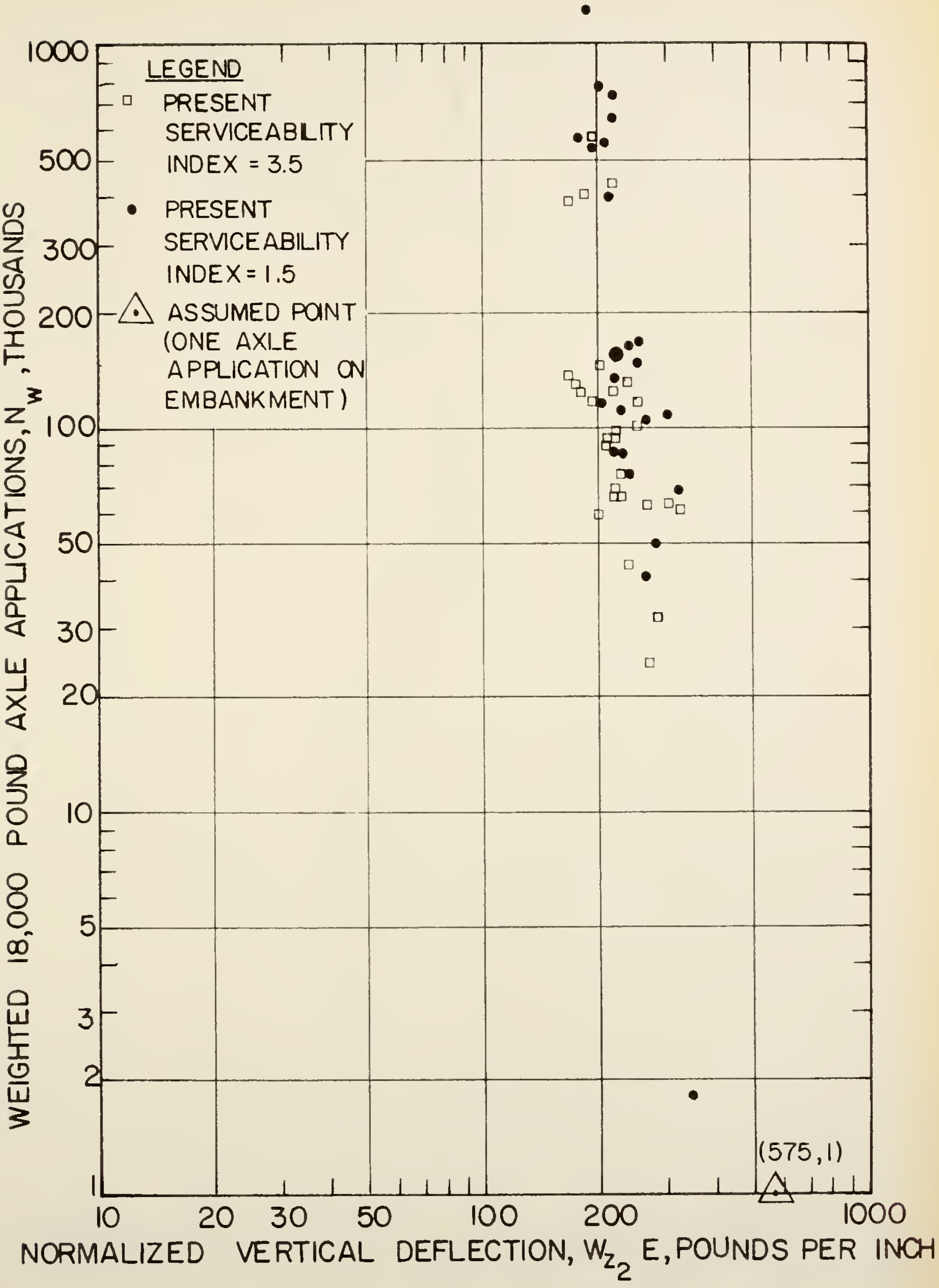


FIGURE 16. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS NORMALIZED VERTICAL DEFLECTION

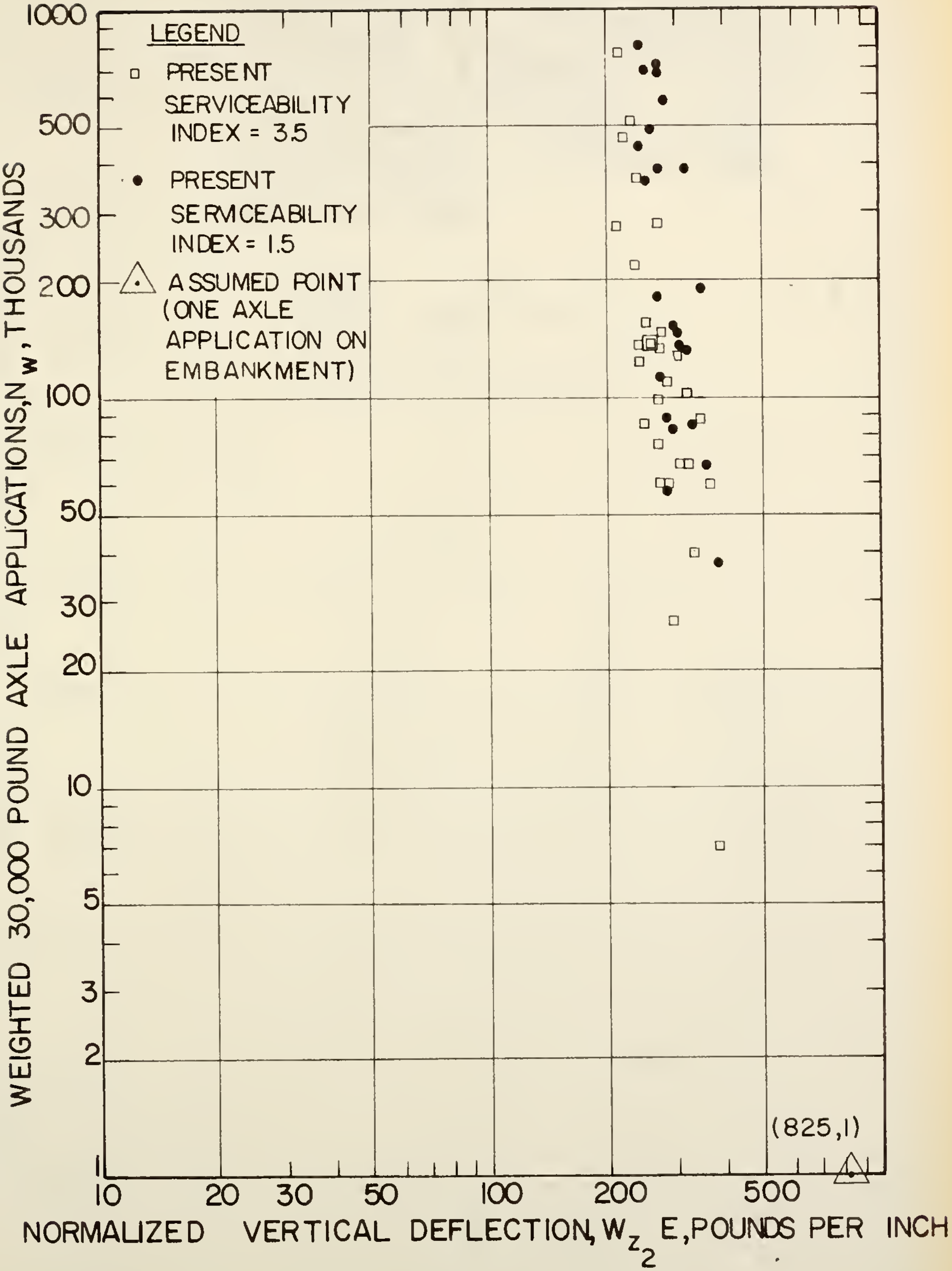


FIGURE 17. WEIGHTED NUMBER OF 30,000 POUND SINGLE AXLE APPLICATIONS VS NORMALIZED VERTICAL DEFLECTION

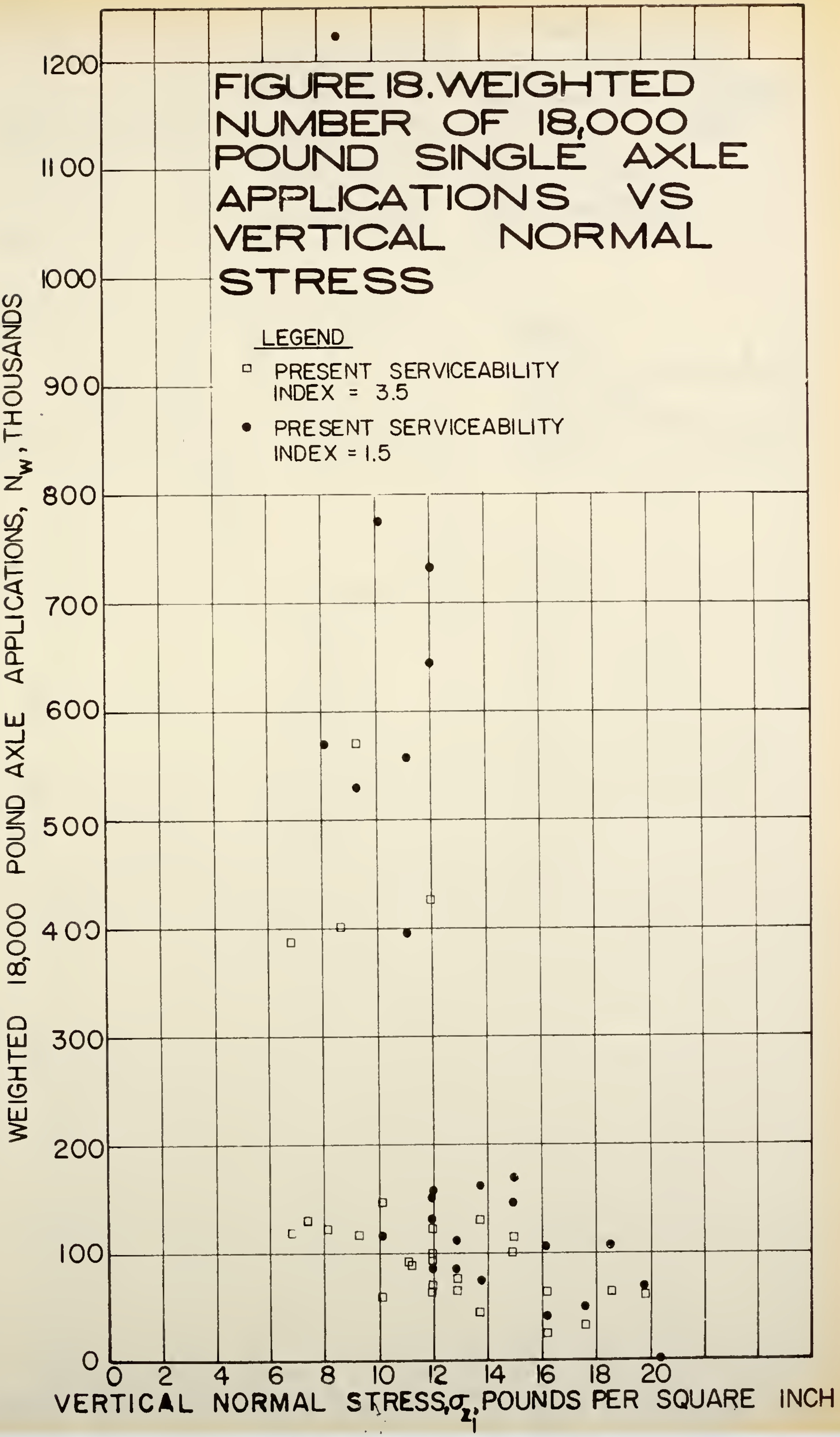


FIGURE 18. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS

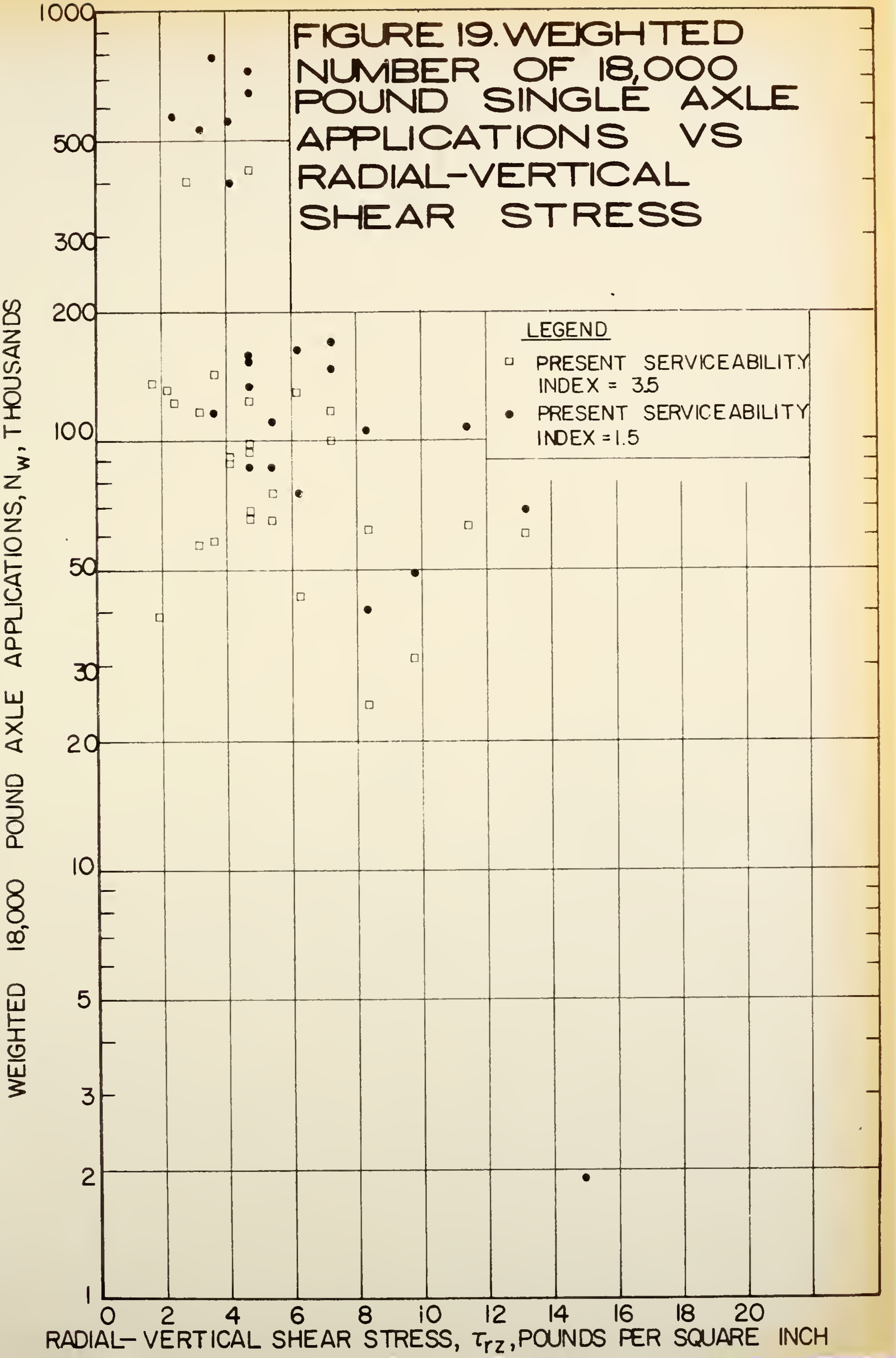


FIGURE 19. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS RADIAL-VERTICAL SHEAR STRESS

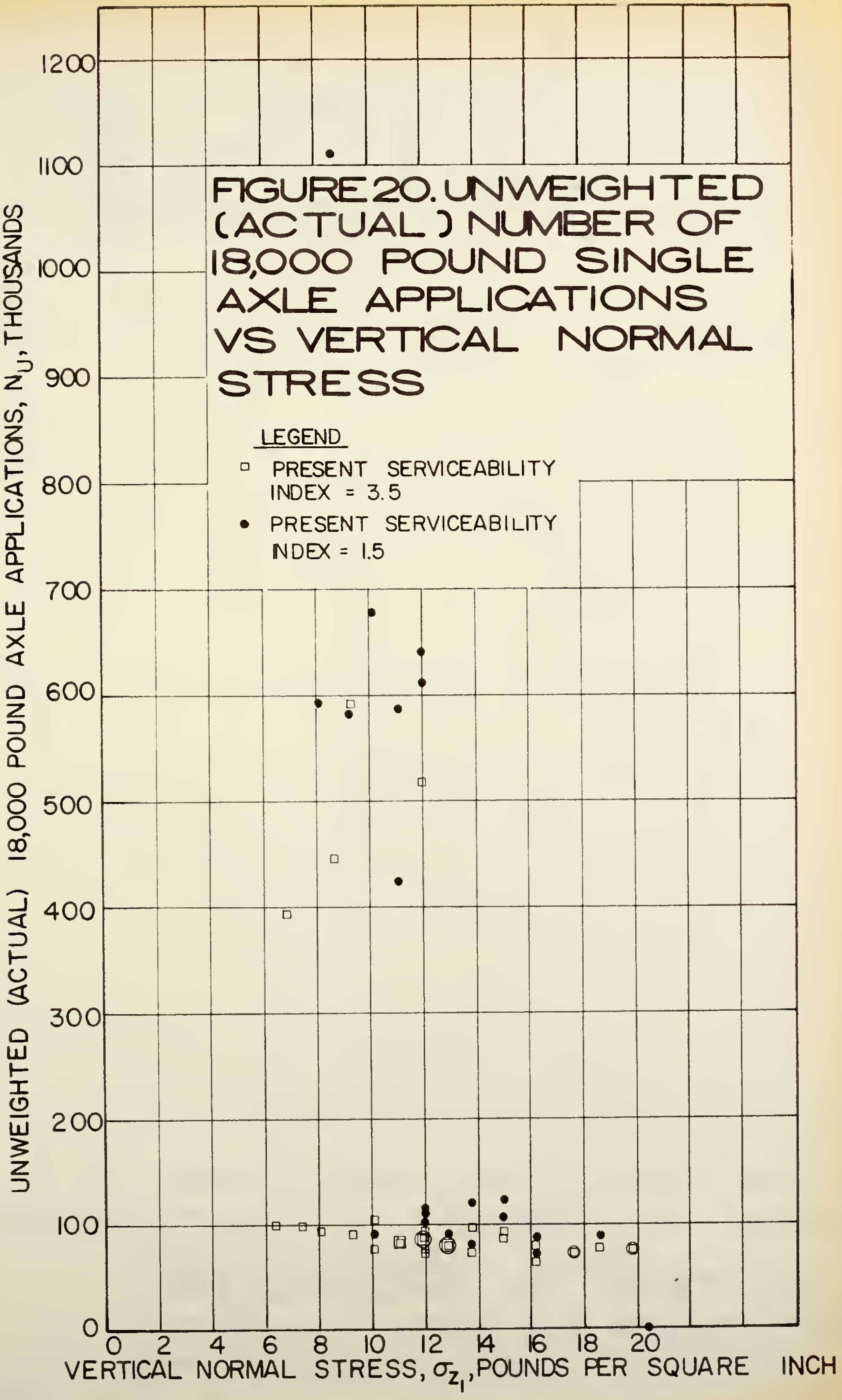


FIGURE 20. UNWEIGHTED (ACTUAL) NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS

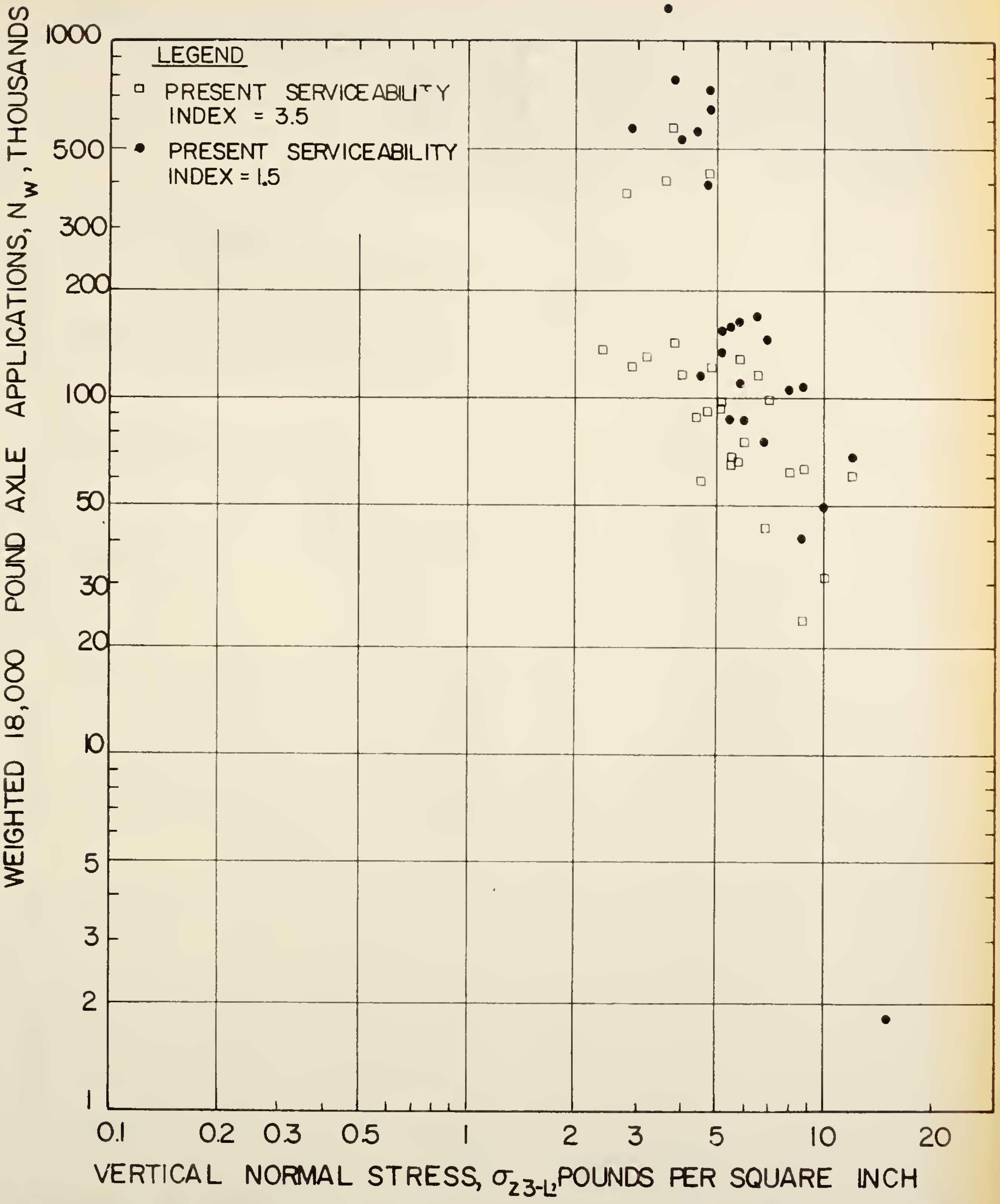
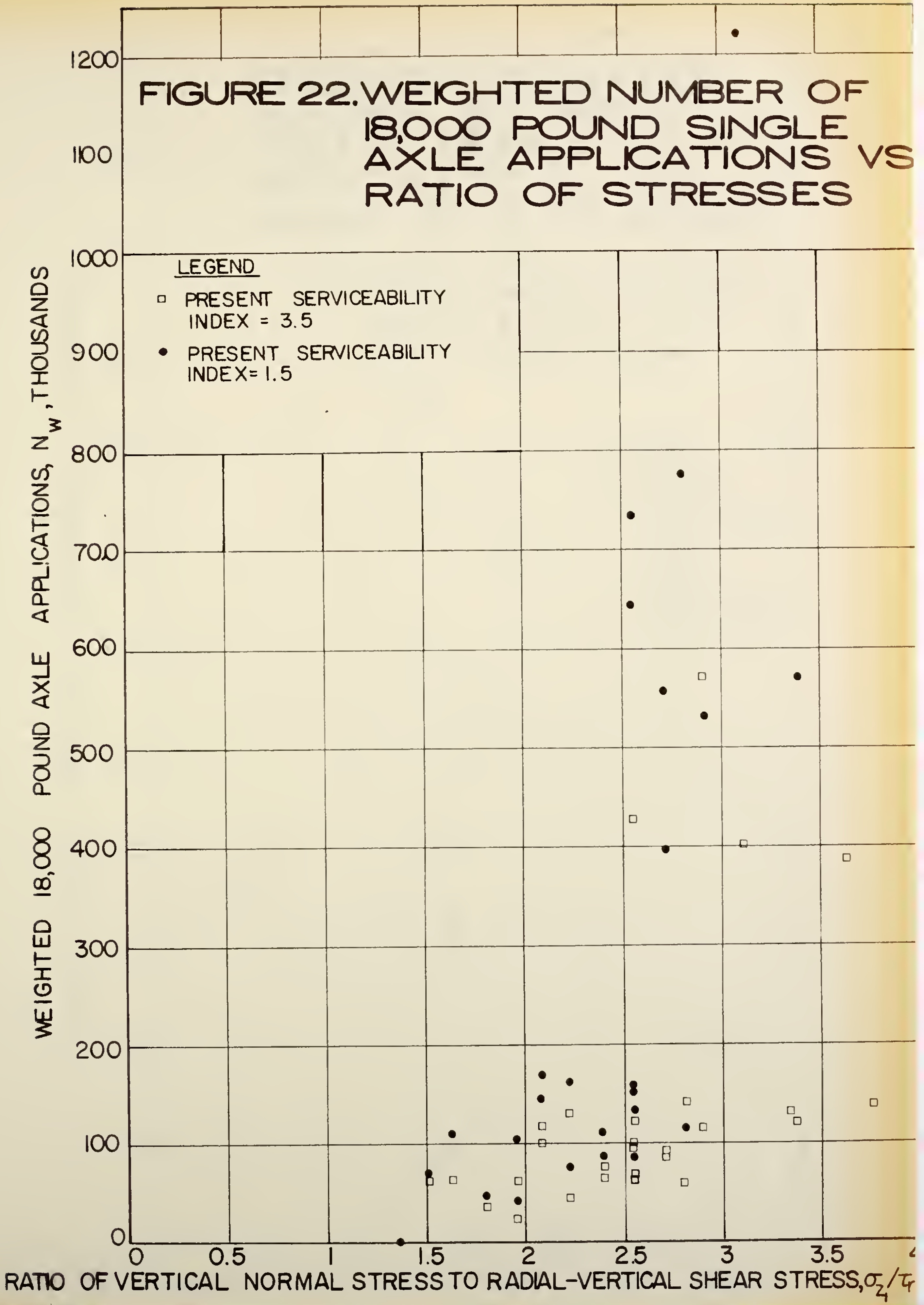


FIGURE 21. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS VERTICAL NORMAL STRESS PREDICTED BY THREE-LAYER THEORY

FIGURE 22. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS RATIO OF STRESSES



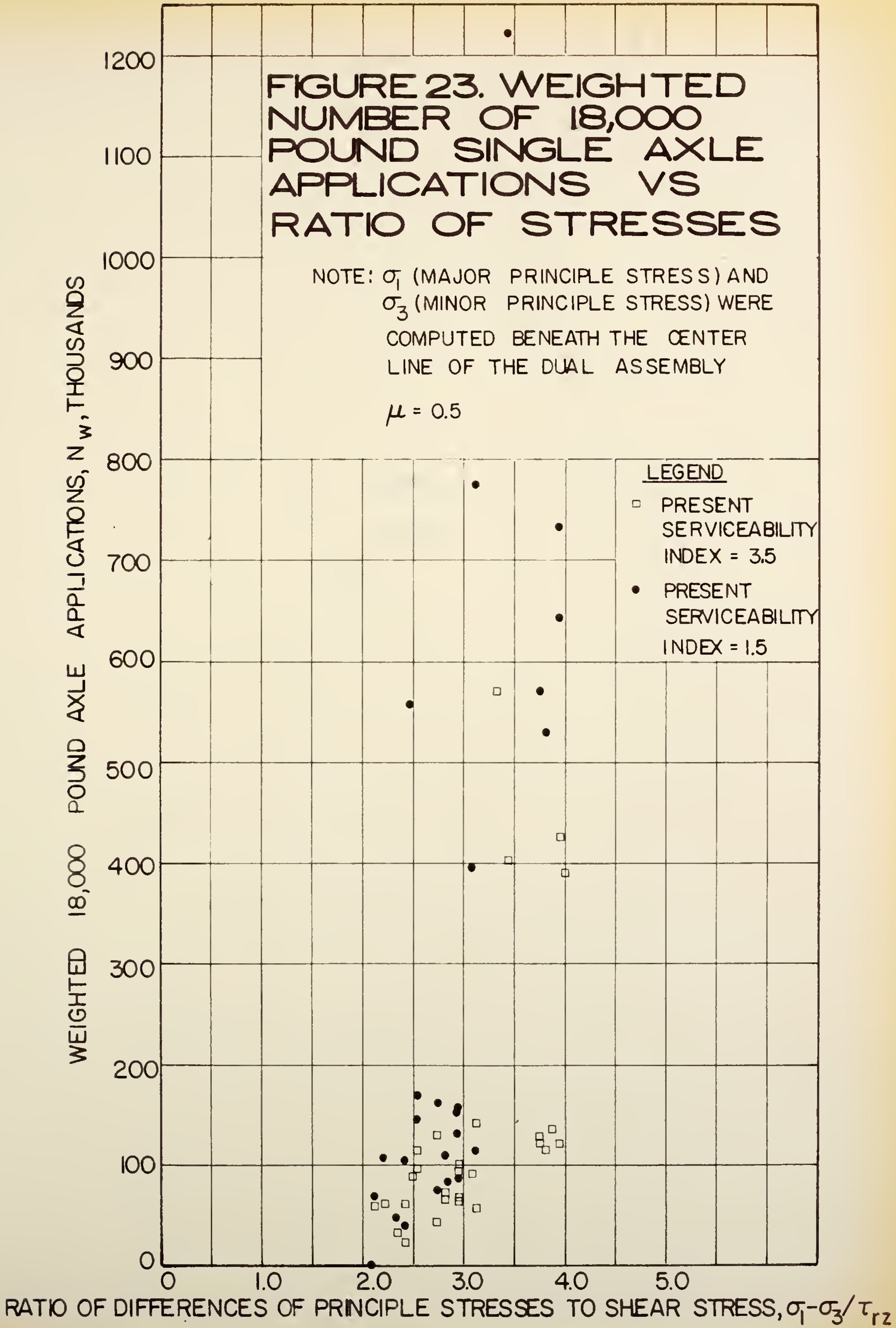


FIGURE 23. WEIGHTED NUMBER OF 18,000 POUND SINGLE AXLE APPLICATIONS VS RATIO OF STRESSES

NOTE: σ_1 (MAJOR PRINCIPLE STRESS) AND σ_3 (MINOR PRINCIPLE STRESS) WERE COMPUTED BENEATH THE CENTER LINE OF THE DUAL ASSEMBLY

$\mu = 0.5$

APPENDIX B

TABLES

TABLE 1. NUMBER OF AXLE APPLICATIONS AND COMPUTED STRESSES[1] AND NORMALIZED DEFLECTIONS[2] (TOP OF EMBANKMENT) FOR THE 6,000 POUND SINGLE AXLE LOAD[3], LOOP 2, LANE 2, DESIGN 1, AASHO ROAD TEST

Section Number	Thickness, In.			Axle Applications to Indicated PSI, Thousands (W = Weighted; U = Unweighted)				Vertical Normal Stress[4], σ_{z_1} (psi)	Radial-Vertical Shear Stress[5], τ_{rz} (psi)	Normalized Vertical Deflection[6], $W_{z_1}E$ (lbs/in)
	Surface	Base	Subbase	N_w 3.5	N_w 1.5	N_u 3.5	N_u 1.5			
722	1	0	0	0.90	2.25	0.70	2.05	0.26	1.22	115
728	1	0	4	1.35	2.70	1.15	2.50	5.85	6.23	121
744	1	3	0	7.02	28.2	7.05	69.5	4.82	6.21	122
718	1	3	4	10.8	43.2	11.4	72.8	6.46	4.64	111
756	1	6	0	12.4	144.6	32.1	106.2	6.57	5.31	115
720	1	6	4	12.4	476.4	32.8	570.2	5.40	2.93	96
772	2	0	0	28.3	49.1	69.5	74.1	1.46	3.65	119
730	2	0	4	19.5	104.7	62.8	87.1	6.47	5.85	118
760	2	3	0	148.1	306.2	108.4	249.5	5.85	6.23	121
732	2	3	0	96.6	163.3	84.7	120.2	5.85	6.23	121
742	2	3	4	146.2	529.7	107.2	582.1	6.16	4.02	106
710	2	3	4	2.70	--	2.50	--	6.16	4.02	106
776	2	6	0	102.1	--	85.9	--	6.46	4.64	111
758	2	6	0	432.5	--	543.2	--	6.46	4.64	111
738	2	6	4	173.4	--	127.4	--	4.97	2.57	92
712	2	6	4	4.50	--	4.30	--	4.97	2.57	92
770	3	0	0	73.3	141.3	79.2	104.2	3.24	5.40	122
740	3	0	4	58.1	144.6	76.0	106.2	6.57	5.31	115

TABLE 1 (Cont'd)

Section Number	Thickness, In.			Axle Applications to Indicated PSI, Thousands (W = Weighted; U = Unweighted)				Vertical Normal Stress[4], σ_{z_1} (psi)	Radial-Vertical Shear Stress[5], τ_{rz} (psi)	Normalized Vertical Deflection[6], $W_{z_1}E$ (lbs/in)
	Surface	Base	Subbase	N_w 3.5	N_w 1.5	N_u 3.5	N_u 1.5			
774	3	3	0	369.9	801.7	356.4	709.6	6.47	5.85	118
746	3	3	4	102.1	--	85.9	--	5.85	3.47	101
750	3	6	0	68.2	--	78.3	--	6.16	4.02	106
764	3	6	4	--	--	--	--	4.60	2.21	89

TABLE 1 (Cont'd)

Section Number	Vertical Normal Stress[7], σ_{z_2} (psi)	Normalized Vertical Deflection[8], $W_{z_2} E$ (lbs/in)	Ratio of Stresses, σ_{z_1} / τ_{rz}	Ratio of Stresses, $\sigma_1 - \sigma_2 / \tau_{rz}$ ($\mu = 0.5$)
722	43.7	238	0.21	2.01
728	18.2	147	0.94	2.20
744	23.4	164	0.78	2.14
718	9.1	113	1.40	2.43
756	11.2	123	1.24	2.35
720	5.9	93	1.85	2.72
772	38.2	218	0.40	2.03
730	14.3	135	1.11	2.28
760	18.2	147	0.94	2.20
732	18.2	147	0.94	2.20
742	8.1	105	1.53	2.52
710	8.1	105	1.53	2.52
776	9.1	113	1.40	2.43
758	9.1	113	1.40	2.43
738	5.2	89	1.93	2.78
712	5.2	89	1.93	2.78
770	30.8	192	0.60	2.09
740	11.2	123	1.24	2.37

TABLE 1 (Concluded)

Section Number	Vertical Normal Stress[7], σ_{z_2} (psi)	Normalized Vertical Deflection[8], $W_{z_2} E$ (lbs/in)	Ratio of Stresses, σ_{z_1}/τ_{rz}	Ratio of Stresses, $\sigma_1 - \sigma_2/\tau_{rz}$ ($\mu = 0.5$)
774	14.3	135	1.11	2.28
746	7.0	99	1.69	2.62
750	8.1	105	1.53	2.52
764	4.6	84	2.08	2.85

[1,2] Boussinesq quantities

[3] Nominal tire pressure = 45 psi; radius of assumed circular contact area = 3.26"; assumed c-c spacing between tires = 13"

[4,5,6] Computed beneath center line of dual tires

[7,8] Computed beneath center of one tire

TABLE 2. NUMBER OF AXLE APPLICATIONS AND COMPUTED STRESSES[1] AND NORMALIZED DEFLECTIONS[2] (TOP OF EMBANKMENT) FOR THE 18,000 POUND SINGLE AXLE LOAD[3], LOOP 4, LANE 1, DESIGN 1, AASHO ROAD TEST

Section Number	Thickness, In.			Axle Applications Thousands				σ_{z_1} [4]	τ_{rz} [5]	$W_{z_1}E$ [6]	σ_{z_2} [7]	$W_{z_2}E$ [8]	σ_z 3-L [9]	σ_{z_1}/τ_{rz}	$\sigma_1-\sigma_3/\tau_{rz}$
	Surface	Base	Subbase	N_w	N_w	N_u	N_u								
				3.5	1.5	3.5	1.5	(psi)	(psi)	(lbs/in)	(psi)	(lbs/in)	(psi)		(μ=0.5)
633	3	0	4	--	1.80	--	1.60	20.4	15.0	342	29.7	349	15.0	1.36	2.07
607	3	0	8	23.9	40.2	66.2	72.1	16.2	8.3	284	16.7	270	8.7	1.95	2.41
571	3	0	12	68.2	85.7	78.2	82.0	12.0	4.7	236	11.0	221	5.5	2.55	2.94
569	3	0	12	64.9	156.7	77.5	115.1	12.0	4.7	236	11.0	221	5.5	2.55	2.94
599	3	3	4	31.2	49.2	70.2	74.3	17.6	9.8	298	18.8	287	10.0	1.80	2.33
573	3	3	8	75.0	85.7	79.6	82.0	12.9	5.4	246	12.1	231	6.0	2.39	2.82
617	3	3	12	115.6	529.7	91.8	582.1	9.3	3.2	209	8.3	195	4.0	2.91	3.81
585	3	6	4	43.2	75.0	72.8	79.6	13.8	6.2	259	13.3	242	6.8	2.23	2.74
623	3	6	8	58.1	115.6	76.0	91.8	10.1	3.6	216	9.1	203	4.5	2.81	3.11
601	3	6	12	129.7	--	97.7	--	7.4	2.2	187	6.7	174	3.2	3.36	3.73
583	4	0	4	59.8	68.2	76.4	78.1	19.8	13.2	329	25.5	326	12.0	1.50	2.12
619	4	0	8	99.3	146.2	85.3	107.1	15.0	7.2	270	15.0	255	7.0	2.08	2.53
603	4	0	12	91.2	395.4	83.4	425.6	11.1	4.1	225	10.0	212	4.7	2.71	3.07
627	4	3	4	61.5	104.8	76.7	87.1	16.2	8.3	284	16.7	270	8.0	1.95	2.41
589	4	3	8	93.8	132.7	84.0	99.5	12.0	4.7	236	11.0	221	5.2	2.55	2.94
597	4	3	8	99.3	151.4	85.3	111.2	12.0	4.7	236	11.0	221	5.2	2.55	2.94

TABLE 2 (Cont'd)

Section Number	Thickness, In. Surface	Thickness, In. Base	Thickness, In. Subbase	Axle Applications Thousands N_w 3.5	N_w 1.5	N_u 3.5	N_u 1.5	σ_{z_1}[4] (psi)	τ_{rz}[5] (psi)	$W_{z_1}E$[6] (lbs/in)	σ_{z_2}[7] (psi)	$W_{z_2}E$[8] (lbs/in)	σ_z 3-L[9] (psi)	σ_{z_1}/τ_{rz}	$\sigma_1-\sigma_3/\tau_{rz}$ (μ=0.5)
575	4	3	12	400.9	1222.0	443.6	1109.2	8.7	2.8	200	7.7	188	3.6	3.11	3.43
595	4	6	4	64.9	110.2	77.5	89.5	12.9	5.4	246	12.1	231	5.8	2.39	2.82
577	4	6	8	570.2	--	591.6	--	9.3	3.2	208	8.3	195	3.8	2.91	3.31
625	4	6	12	388.2	--	391.7	--	6.9	1.9	182	6.3	169	2.8	3.63	4.00
605	5	0	4	63.2	107.4	77.1	88.3	18.6	11.4	313	21.6	305	8.8	1.63	2.21
587	5	0	8	129.4	161.8	97.7	119.1	13.8	6.2	258	13.3	242	5.8	2.23	2.74
621	5	0	12	141.3	774.5	104.3	676.1	10.1	3.6	216	9.1	203	3.8	2.81	3.11
579	5	3	4	115.6	169.1	91.8	124.4	15.0	7.2	270	15.0	255	6.5	2.08	2.53
631	5	3	8	88.5	557.2	82.8	587.5	11.1	4.1	225	10.0	212	4.4	2.71	2.47
593	5	3	12	121.3	570.2	94.2	591.6	8.1	2.4	194	7.2	180	2.9	3.38	3.75
629	5	6	4	424.6	732.8	518.8	639.7	12.0	4.7	236	11.0	221	4.8	2.55	3.94
615	5	6	4	121.3	644.2	94.2	611.0	12.0	4.7	236	11.0	221	4.8	2.55	3.94
591	5	6	8	--	--	--	--	8.7	2.8	200	7.7	188	3.6	3.11	3.43
581	5	6	12	136.5	--	101.6	--	6.4	1.7	175	5.9	169	2.4	3.76	3.88

[1,2] Boussinesq quantities unless otherwise noted

[3] Nominal tire pressure = 75 psi; radius of assumed circular contact area = 4.37"; assumed c-c spacing between tires = 13"

[4,5,6] Computed beneath center line of dual tires

[7,8] Computed beneath center of one tire

[9] Vertical normal stress predicted by three layer theory

TABLE 3. NUMBER OF AXLE APPLICATIONS AND COMPUTED STRESSES[1] AND NORMALIZED DEFLECTIONS[2] (TOP OF EMBANKMENT) FOR THE 30,000 POUND SINGLE AXLE LOAD[3], LOOP 6, LANE 1, AASHO ROAD TEST

Section Number	Thickness, In.			Axle Applications, Thousands										
	Surface	Base	Subbase	N_w 3.5	N_w 1.5	N_u 3.5	N_u 1.5	σ_{z_1}[4] (psi)	τ_{rz}[5] (psi)	$W_{z_1}E$[6] (lbs/in)	σ_{z_2}[7] (psi)	$W_{z_2}E$[8] (lbs/in)	σ_{z_1}/τ_{rz}	$\sigma_1-\sigma_3/\tau_{rz}$
269	4	3	8	7.02	37.2	7.05	71.4	19.4	7.2	392	19.0	384	2.69	2.78
299	4	3	12	101.9	384.6	85.9	371.4	14.1	4.3	331	13.6	323	3.28	3.49
317	4	3	16	75.1	182.8	79.6	134.0	10.6	2.8	280	10.3	275	3.79	3.74
329	4	3	16	59.9	113.0	76.4	90.6	10.6	2.8	280	10.3	275	3.79	3.74
303	4	6	8	40.2	85.7	72.1	82.0	15.2	4.9	346	14.8	336	3.10	3.16
323	4	6	12	58.1	88.5	76.0	82.8	11.2	3.0	294	11.0	287	3.73	3.79
253	4	6	16	136.2	446.7	101.4	550.8	8.6	2.2	252	8.5	248	3.91	3.89
321	4	9	8	26.7	83.0	68.4	81.5	12.2	3.4	304	11.8	298	3.59	3.50
267	4	9	12	85.7	366.4	82.0	352.3	9.2	2.4	261	8.9	256	3.83	3.83
309	4	9	16	466.7	--	563.6	--	7.0	1.7	230	7.0	226	4.12	4.12
319	5	3	8	59.8	68.2	76.4	78.2	17.9	6.4	376	17.5	368	2.80	2.90
261	5	3	12	68.2	134.6	78.2	100.5	13.1	3.9	318	12.7	310	3.36	3.38
315	5	3	16	138.1	489.8	102.3	572.8	9.8	2.6	270	9.5	266	3.77	3.79
259	5	6	8	68.2	132.7	78.2	99.5	14.1	4.3	331	13.6	323	3.28.	3.42
307	5	6	12	141.3	724.5	104.2	633.9	10.6	2.8	280	10.2	275	3.79	3.69
305	5	6	12	99.3	391.7	85.3	411.1	10.6	2.8	280	10.2	275	3.79	3.69
327	5	6	16	366.5	--	352.3	--	8.0	2.0	244	8.0	241	4.00	3.93

TABLE 3 (Cont'd)

Section Number	Thickness, In.			Axle Applications, Thousands				σ_{z_1}[4]	τ_{rz}[5]	$W_{z_1}E$[6]	σ_{z_2}[7]	$W_{z_2}E$[8]	σ_{z_1}/τ_{rz}	$\sigma_1-\sigma_3/\tau_{rz}$
	Surface	Base	Subbase	N_w 3.5	N_w 1.5	N_u 3.5	N_u 1.5	(psi)	(psi)	(lbs/in)	(psi)	(lbs/in)		
313	5	9	8	110.2	583.4	89.5	594.3	11.2	3.0	294	11.0	287	3.73	3.63
331	5	9	12	121.4	811.0	94.2	717.8	8.6	2.2	252	8.5	248	3.91	3.89
265	5	9	16	769.2	--	669.9	--	6.7	1.6	222	6.3	220	4.19	4.28
297	6	3	8	88.5	189.7	82.8	140.9	16.0	5.5	361	16.1	351	2.91	3.05
335	6	3	12	59.9	153.1	76.4	112.5	12.2	3.4	304	11.8	298	3.59	3.50
255	6	3	16	158.1	701.5	116.4	626.6	9.2	2.4	261	8.9	256	3.83	3.83
325	6	6	8	129.4	144.6	97.7	106.2	13.1	3.9	318	12.7	310	3.36	3.38
257	6	6	12	138.2	--	102.6	--	9.8	2.6	270	9.6	266	3.77	3.79
301	6	6	16	516.4	--	579.4	--	7.5	1.9	236	7.5	234	3.95	4.03
263	6	9	8	131.2	690.3	98.6	623.8	10.6	2.8	280	10.2	275	3.79	3.69
271	6	9	8	282.5	--	224.9	--	10.6	2.8	280	10.2	275	3.79	3.69
311	6	9	12	220.3	--	166.7	--	8.0	2.0	244	8.0	241	4.00	2.63
333	6	9	16	275.4	--	216.8	--	6.3	1.6	217	6.3	214	3.94	4.15

[1,2] Boussinesq quantities

[3] Nominal tire pressures 80 psi; radius of assumed circular contact area = 5.46"; assumed c-c spacing between tires = 13"

[4,5,6] Computed beneath center line of dual tires

[7,8] Computed beneath center of one tire

APPENDIX C

BIBLIOGRAPHIC ABBREVIATIONS AND CODING SYSTEM SYMBOLS

(Note: The abbreviations and symbols defined herein pertain to Phase 2 of HRB Project 1-4(2); Appendix D contains the literature in codified form.)

[illegible]

[illegible]
[illegible]

[illegible]
[illegible]
(Leased Buildings [illegible]

BIBLIOGRAPHIC ABBREVIATIONS

ABBREVIATION	MEANING
AAPT	The Association of Asphalt Paving Technologists
ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
Bull.	Bulletin
HRB	Highway Research Board
ICSDAP	International Conference on the Structural Design of Asphalt Pavements
ICSMFE	International Conference on Soil Mechanics and Foundation Engineering
No.	Number
Trans.	Transactions
Vol.	Volume

CODING SYSTEM SYMBOLS

NUMBER	CATEGORY	SYMBOL	MEANING OF SYMBOL
I	General nature of the article; type of problem presented and basic method of solution	A	Analysis and/or discussion of AASHO Road Test data
		$C_v(T_e)$	Combined; experimental results compared with or used to substantiate results predicted by (elastic theory)
		$C_v(T_v)$	Combined; -- (viscoelastic theory)
		$C_v(T_l^e)$	Combined; -- (elastic layered theory)
		$C_v(T_l^v)$	Combined; -- (viscoelastic layered theory)
		D	Dimensional analysis
		E	Experimental; experimental results presented
		T_e	Theoretical; elastic
		T_l	Theoretical; layered system
		T_{sm}	Theoretical; elementary strength of materials
		T_v	Theoretical; viscoelastic
		T_l^{ce}	Theoretical; critical equilibrium of layered system
		T_l^e	Theoretical; elastic layered system
		T_l^v	Theoretical viscoelastic layered system
		S	Survey article

NUMBER	CATEGORY	SYMBOL	MEANING OF SYMBOL
II_A	Assumptions relative to properties of loaded layer	C	Compression resistance characterized by units of lbs/ft^3
II_B	Assumptions relative to properties of second layer	E	Layer possesses elastic properties
II_C	Assumptions relative to properties of remaining layer(s)	H	Layer is homogeneous, elastic and isotropic
		N	Layer properties not specified
		P - C	Layer possesses ϕ and c properties
		R_f	Rigid surface; friction developed
		S	Shearing tendency characterized by units of lbs/ft^2
		V	Layer possesses viscoelastic properties
		W	Winkler layer

NUMBER	CATEGORY	SYMBOL	MEANING OF SYMBOL
III_A	Composition of loaded layer	A	Asphaltic concrete
		AC	Asphalt cement
III_B	Composition of second layer	E	Embankment; material not specified
III_C	Composition of remaining layer	L	Landing mats
		N	Composition not specified
		P	Portland cement concrete
		PL	Plungers supported by calibrated springs
		P_{ps}	Portland cement concrete, pre-stressed
		R	Rock; composition not otherwise specified
		RS	Rubber slab
		S	Soil; composition not otherwise specified
		S_c	Soil; coarse grain - granular
		S_f	Soil; fine grain - clay
		S_s	Soil; fine grain - silt
		S_{cf}, S_{cs} S_{fs}, S_{sf}, etc.	Soil; mixed - sandy clay, sandy silt, clayey silt, silty clay, etc.
		S_{ce}	Soil cement
		SL	Slag
		SLVS	Steel leaves
		SPPC	Steel plates containing pressure-sensitive cells
		G	Tar

NUMBER	CATEGORY	SYMBOL	MEANING OF SYMBOL
IV_A	Type of load	$D^c(C)$	Dynamic; circular area - constant velocity
		$D^n(C)$	Dynamic; concentrated - constant velocity
		D_d	Dynamic; dual tires
		D_{d-s}	Dynamic; dual tires - single axle
		D_{d-t}	Dynamic; dual tires - tandem axle
		D_f	Dynamic; friction developed between tires and pavement and between surface layer and base
		D^r	Dynamic; rectangular area
		D_s	Dynamic; single wheel
		D_t	Dynamic; truck
		D_{tw}	Dynamic; twin wheel loading
		D_{twt}	Dynamic; twin - tandem loading
		D_{u-p}	Dynamic; uniform pulse
		G	Gravity acting only
		I	Impact loads
		M	Multi-compartment tires
		N	No external load applied
		P	Penetration loading - penetrometer driven by falling weight
		P_{cbr}	Penetration loading - CBR
		PP	Penetrating plunger
		R^c	Repetitive; circular area
		R_t	Repetitive; triaxial
		S^a	Static; any area
		S^c	Static; circular area
		S^n	Static; concentrated

NUMBER	CATEGORY	SYMBOL	MEANING OF SYMBOL
IV_A (cont'd)	Type of load	S^r	Static; rectangular area
		S_c^c	Static; circular area - conical load
		S_d	Static; dual wheels
		S_d^c	Static; circular area - dual wheels
		S_d^e	Static; elliptical area - dual wheels
		S_d^r	Static; rectangular area with rounded ends - dual wheels
		S^e	Static; elliptical area
		S_e^g	Static; general embankment
		S_e^r	Static; rectangular embankment
		S_e^t	Static; triangular embankment
		S_e^{tr-s}	Static; symmetrical trapezoidal embankment
		S_e^{tr-u}	Static; unsymmetrical trapezoidal embankment
		S_l	Static; line load
		S_m	Static; multiple wheels
		S_m^c	Static; circular area - multiple wheels
		S_n^c	Static; circular area - non-uniformly applied load
		S^p	Static; parabolic area
		S_r	Static; rigid plate
		S_s	Static; single wheel
		S_s^c	Static; circular area - single wheel
		S_s^e	Static; elliptical area - single wheel
		S_s^r	Static; rectangular area with rounded ends - single wheel
		S^{sc}	Static; semi-circular area

NUMBER	CATEGORY	SYMBOL	MEANING OF SYMBOL
IV_A (cont'd)	Type of load	S_t	Static; tangential load
		S_t^r	Static; rectangular area - tangential load
		S_u^c	Static; circular area - uniform load
		S_u^r	Static; rectangular area - uniform load
		S_u^s	Static; strip - uniform load
		S_u^{sc}	Static; semi-circular area - uniform load
		S_u^{sq}	Static; square area - uniform load
		V	Vibrational loading
IV_B	Position of load	C	Corner of slab
		CH	Channelized
		E	Edge of slab
		I	Interior of slab
		M	Moving
		S	Load on surface

NUMBER	CATEGORY	SYMBOL	MEANING OF SYMBOL
V_A	Ambient effects; temperature	T	Warping stresses caused by temperature gradients considered
		T_g	Temperature gradients controlled to eliminate effects
		T_{gr}	Temperature gradients measured
		T_o	Temperature changes considered
V_B	Ambient effects; moisture	M	Warping stresses caused by moisture gradients considered
		M_g	Moisture gradients controlled to eliminate effect
		M_o	Moisture changes considered

APPENDIX D

CODIFIED LITERATURE

Aaron, H., Allen, H., Horonjeff, R., Pickett, G., Johannessen, W., "A comparison of Design Methods for Airfield Pavements", *Proc.*,ASCE, Vol. 78, Separate 163, (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S.											

I. Five pavement design methods considered:
  - a. CAA
  - b. Corps of Engineers (CBR)
  - c. McLeod
  - d. Navy
  - e. Westergaard

Ahlberg, Harold L. and Barenberg, Ernest J., "The University of Illinois Pavement Test Track- A Tool for Evaluating Highway Pavements." *Highway Research Record No. 13,* HRB, pp. 1-21 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S, E	N	N	--	A, *, **	S_c, S_{ce}	--	D_s		--	--	

I. Paper contains description of test track.

*. Sand slurry seal

**. Mortar

Ahlvin, R. G., "Direct Measurement of Shear Stresses in Soil Mass", Proc., HRB, Vol. 33, pp. 471-474 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_c	--	--	S_u^c	S	--	--	

Ahlvin, R. G. and Ulery, H. H., "Tabulated Values for Determining the Complete Pattern of Stresses, Strains and Deflections Beneath a Uniform Circular Load on a Homogeneous Half Space", Bull. 342, HRB, pp. 1-13 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S_u^c	S	--	--	

Allen, Harold, "Report of Committee on Warping of Concrete Pavements", Proc., HRB, Vol. 25, pp. 199-250 (1945).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	P	*	*	--	--	T, T_o	M, M_o	

* Numerous combinations of materials discussed.

Baker, Robert F. and Papazian, Hratch, "The Effect of Stiffness Ratio on Pavement Stress Analysis", Proc., HRB, Vol. 39, pp. 61-85 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e,	H,	H	--	A,	N,	--	S_r^c,	S,	T	M	
T_v,	V			P	SLVS		S_s^c	C,			
T_1^e,							S^n,	I			
$C_v(T_e)$							S^r				

Baker, Robert F., "A Structural Design Procedure for Pavements", Proc., ICSDAP, pp. 465-475 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e, T_1^v	H	E	E	A	N	N	S^c	N	T_o	--	

IV_a. Effects of dynamic loading considered.

V_a. Temperature effects implicit in discussion of complex modulus of elasticity.

Barber, E. S., "Application of Triaxial Compression Test Results to the Calculation of Flexible Pavement Thickness", Proc., HRB, Vol. 26, pp. 26-39 (1946).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H, P-C	H, P-C	--	A	S	--	S^c	S	--	M_o	

Barber, Edward S., "Shear Loads on Pavements", Proc., ICSDAP, pp. 354-357 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S^c	S	--	--	

Baron, Francis M., "Variables in the Design of Concrete Runways of Airports", Proc., HRB, Vol. 22, pp. 225-239 (1942).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	N	N	--	S_u^c, S_u^e, S_u^{sc}, S_n^c	I	--	--	

Benkelman, A. C., "Report of Committee on Flexible Pavement Design", Proc., HRB, Vol. 23, pp. 90-100 (1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Paper describes design methods in use and outlines design method based on large-scale loading tests of trial pavement sections.

Benkelman, A. C. and Williams, Stuart, "The Structural Behavior of Flexible Pavement. An Analysis of Rigid-Plate Bearing Tests on Full-Size Test Sections", Proc., ICSDAP, pp. 686-712 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S_c	S_f^{cl}	R^c	S	T_o	--	

Bernhard, R. K., "Highway Investigation by Means of Induced Vibrations", Bull. No. 49, The Pennsylvania State College Engineering Experiment Station, Vol. 33, pp. 1-29 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P, S_s	S_s	--	V	S	--	--	

Bradbury, R. D., "Evaluation of Wheel-Load Distribution for the Purpose of Computing Stresses in Concrete Pavements", Proc., HRB, Vol. 14, pp. 225-254 (1934).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S_s^c, S_s^{sc}, S_d^c, S_d^{sc}	C, I, E	--	--	

Broms, Bengt B., "Effect of Degree of Saturation on Bearing Capacity of Flexible Pavements", Highway Research Record No. 71, HRB, pp. 1-14 (1965)

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T^{ce}	N	N	P-C	A	N	S_f	*	*	--	M_o	

* Applied load assumed to be distributed over an area which increases linearly with distance from the point of loading.

Brown, Philip P., "Analysis of Flexible Airfield Pavements by Surface Plate Loading", Proc., ICSDAP, pp. 680-685 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_1^e)$	H	E	--	A	*	*	S^c	S	--	--	

* Various base and subgrade materials tested.

Brzesowsky, R. A. and Vanderveen, C., "An Investigation on the Capacity of Some Flexible Runways at Schiphol Airport", Proc., Third ICSMFE, Vol. 2, pp. 97-102 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S_c	S_c, S_f	R^c	S	--	M_o	

Burggraf, F., "Field Tests on Bearing Capacity, Shearing and Penetration Resistance of Soils", Proc., HRB, Vol. 20, pp. 287-298 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	A, S	S --	S --	P, S^r, S^p	S	--	M_o	

Burmister, Donald M., "The Theory of Stresses and Displacements in Layered Systems and Applications to the Design of Airport Runways", Proc., HRB, Vol. 23, pp. 126-148, (1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H, E	E	--	P, A, S	N	--	S_u^c	I, S	--	--	

Burmister, Donald M., "Stress and Displacement Characteristics of a Two-Layer Rigid Base Soil System: Influence Diagrams and Practical Applications", *Proc.*. HRB, Vol. 35, pp. 773-814 (1956).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	S, A, P	S_f, S_c	-- S_f	S^n, S_u^c, S^a, S_r^c	S, I	--	--	

Burmister, Donald M., "Applications of Layered System Concepts and Principles to Interpretations and Evaluations of Asphalt Pavement Performances and to Design and Construction", Proc., ICSDAP, pp. 441-453 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	E	E	A	S_c	N	S^c	S	--	--	

Carlton, Paul F. and Behrmann, Ruth M., "A Model Study of Rigid Pavement Behavior Under Corner and Edge Loadings", Proc., HRB, Vol. 35, pp. 139-146 (1956).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	P	RS	--	S^c, S^e	C, E	T_g	M_g	

Carey, W. N. Jr. , Irick, P. E., "The Pavement Service Ability Performance Concept", Bull. 250, HRB, pp. 40-58 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
*											

* Paper presents system whereby pavement performance can be determined quantitatively; the system was developed at the AASHO Road Test.

Childs, L. D., "A Study of Slab Action in Concrete Pavements under Static Loads", Proc., HRB, Vol. 27, pp. 64-84 (1947).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E,	N	N	N	P	S_c	S_c	S_d,	E,	T_g	M_g	
$C_v(T_e)$	H	W	--				S^c,	C			
							S_s				

Cholnoky, Thomas, "Prestressed Concrete for Airfields", Journal, ACI, Vol.28, pp. 59-84, July 1956.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	P	S_c	S_f	S_r^c	I,	T_{gr}	M_o	
								E			

Claudon, J. G., "Study of Stresses in Prestressed Concrete Pavements at Maison-Blanche Airport", Highway Research Record No. 44, HRB, pp. 80-103 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, *	E	N	N	P_{ps}	S_c	S_{cf}	**	--	T_o	M_o	

* Theoretical relationship developed between stresses and hygrothermal changes.

** Stresses induced by additional prestress observed; also observed were variations of stresses with changes in temperature, moisture content, and time.

Colley, B. E. and Nowlen, W. J., "Performance of Subbases for Concrete Pavements Under Repetitive Loading", Bull. 202, HRB, pp. 32-58 (1958).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	P_{ps}	S_c	S_f	R^c	S	--	M_o	

Croney, D., Salt,G. F., "Three Full-Scale Roads Experiments and their Implication in Relation to Pavement Design", Proc., Fifth ICSMFE, Vol. 2, pp. 199-206 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A,	A, R	R, S_f	*	M	--	--	

* Highway Traffic

Davis, E. H., "Pavement Design for Roads and Airfields", Road Research, Technical Paper No. 20, Road Research Laboratory, Harmondsworth, England (1951).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

DeKruyf, M, van der Poel, C., Timman, R., "Calculation of Stresses in Road and Runway Construction", Proc., Second ICSMFE, Vol. 4, p. 181 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	H	H	P	S_c	S_c	S_s, S_d,	S	--	--	

c

S_u

de L'Hortet, R. and Dreyfuss, G., "Bearing Capacity of Flexible Runways", Proc., Third ICSMFE, Vol. 2, pp. 107-111 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	N	--	A	S	--	S_u^c	S	--	M_o	

Dingwall, J. C. and Scrivner, F. H., "Application of the Elastic Theory to Highway Embankments by Use of Difference Equations", Proc., HRB, Vol. 33, pp. 474-482 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	R_f	--	E	N	--	G	--	--	--	

Docker, C. E. and McFeeters, J. N., "Principles on Concrete Runway Design", Proc.. Second ICSMFE, Vol. 2, pp. 246-256 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	P	N	--	S_u^c	I,	T,	--	
							S_u^e ,	E,	T_{gr}		
							I	C			

Docker, C. E., McFeeters, J. N., "An Example of Concrete Runway Design With Critical Comments", Proc., Second ICSMFE, Vol. 2, p. 263 (1948)

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	S_{fs},	--	S_s^c	I,	T	--	
					P			E,			
								C			

Dorman, G. M., "The Extension to Practice of a Fundamental Procedure for the Design of Flexible Pavements", Proc., ICSDAP, pp. 785-793 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	E	E	A	S_c	N	D_d	S	T_o		

Dunlap, Wayne A., and Stark, L. E., "Deflection Tests on Texas Highways", Bull. 269, HRB, pp. 52-65 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S, S_f	S, S_f	S_d	S	T_o	--	

IV_a. Creep speed deflections determined by Benkelman beam.

ERROR made in page numbering - Page No. 24.

Ewell. W. W. and Okubo, S., "Deflections in Slabs on Elastic Foundations", *Proc.*, HRB, Vol. 30, pp. 125-133 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_{sm}	H	W	--	N	N	--	S^n	I	--	--	

Fergus, Stuart M. and Miner, William E., "Distributed Loads on Elastic Foundations: The Uniform Circular Load", *Proc.*, HRB, Vol. 34, pp. 582-597 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S_u^c, S_s^c	S	--	--	

Ferreira, H. N., Campinos, J. F. P., " A Mathematical Method of Determining the Thickness of Flexible Pavements, Based on the California Bearing Ratio", Proc., Fifth ICSMFE, Vol. 2, pp. 235-238 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S_s	S	--	--	

Fordyce, Phil and Teske, W. E., "Some Relationships of the AASHO Road Test to Concrete Pavement Design". Highway Research Record No. 44, HRB, pp. 35-70 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A											

Paper considers only Portland cement concrete sections.

Foster, Charles R. and Fergus, S. M., "Stress Distribution in a Homogeneous Soil", Special Report No. 12-F, HRB, January 1951.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	--	--	S_{fs}	--	--	S^c	S	--	--	

IV_a. Single and dual loads applied through flexible plates.

IV_b. Position on surface varied but was specified.

Foster, C. R., "Reduction in Soil Strength with Increase in Density", Trans., ASCE, Vol. 120, pp. 803-815 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	L	S_{sf}	--	D_s, D_d	S , M	--	M_o	

Foster, Charles R., "Failure Criteria for Flexible Airfield Pavements", Bull. 187, HRB, pp. 72-76 (1958).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Fox, L., "Computation of Traffic Stresses in a Simple Road Structure", Road Research Technical Paper No. 9, Road Research Laboratory, Harmondsworth, England (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	H	--	N	N	--	S_u^c	S	--	--	

Freeman, Ralph A., "Flexible Pavement Test Sections for 300,000 lb. Airplanes, Stockton, California", Proc., HRB, Vol. 25, pp. 23-44 (1945).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S_c	S_f, --	S_s, D_s	S, M	T_o	--	

Freitag, D. R., and Knight S. J., "Stresses in Yielding Soils Under Moving Wheels and Tracks", Bull. 342, HRB, pp. 24-37 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e^e)$	H	--	--	S_f, S_c	--	--	*	S	--	--	

I. Boussinesq analysis used in comparison of results with theory.

* Dynamic loads imposed by various types of tracked vehicles and by a conventional truck (single tires, tandem axle).

Freitag, D. R., Green, A. J., and Murphy, N. R. Jr., "Normal Stresses at the Tire- Soil Interface in Yielding Soils", Highway Research Record No. 74, HRB, pp. 1-18 (1965).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_f, S_c	--	--	D_s	S	--	--	

IV_a. Tire mounted in a single-wheel test carriage; tire was either towed or powered.

Freitag, D. R. and Green, A. J. "Distribution of Stresses on an Unyielding Surface Beneath a Pneumatic Tire", Bull. 342, HRB, pp. 14-23 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	SPPC	--	--	S_s	S	--	--	

IV_a. Various types of tires (no tread) tested.

IV_b. Position of tire specified.

Geldmacher, R. C., Anderson, R. L., Dunkin, J. W., Partridge, G. R., Harr, M. E., and Wood, L. E., "Subgrade Support Characteristics as Indicated by Measurements of Deflection and Strain", Proc., HRB, pp. 479=496 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N, H	N	--	P	S_{ce} S_c, S_f	--	D_d	M E I	T	--	

II_a. Assumption of homogeneity involved in supplementary study.

Gillette, H. S., "Stresses Under Circular Flexible Foundations", Bull. 277, HRB, pp. 61-74 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S_u^c	S	--	--	

Influence charts (stress contours) for Boussinesq problem.

Goldbeck, A. T., "Traffic Stresses Produced in Concrete Roads", Proc., HRB, Vol. 4, pp. 62-63 (1924).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	N	--	D_t	M, I, E, C	--	--	

Goldbeck, A. T., "Studies of Subgrade Pressures Under Flexible Road Surfaces", Proc., HRB, Vol. 19, pp. 164-174 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_c	S_{cf}	S^e, S^c	S^e, S^c	S	--		

Goldbeck, A. T., "A Method of Design of Non-Rigid Pavements for Highways and Airport Runways", Proc., HRB, Vol. 20, pp. 258-270 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_{sm}, E	N	N	--	N	S	--	S^e	S	--	--	

Glossop, R., Golder, H. Q., "The Shear Strength Method of the Determination of Pavement Thickness", Proc., Second ICSMFE, Vol. 4, p. 164 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	H	H, P-C	--	P, N	S_f, S_c, S_{cf}	--	S_u^c	S	--	--	

Hank, R. J. and Scrivner, F. H., "Some Numerical Solutions of Stresses in Two- and Three-Layered Systems", Proc., HRB, Vol. 28, pp. 457-468, (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_1^e)$, T_1^ϵ	H	H	--, H	S_{ce}, P	A, S_f, S_c	S_f, --	S_u^c	S, I	--	--	

Hardy, R. M. and Rivard, P. J., "Stress Distributions Below Pavements Under Trolley Bus Loadings", Proc., HRB, Vol 30, pp. 396-406 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	--	--	A, P	S_c S_f	--	S_s, S_d, D_s, D_d	S	--	--	

Harr, M. E. and Leonards, G. A., "Warping Stresses and Deflections in Concrete Pavements", Proc., HRB, Vol. 38, pp. 286-320 (1959).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e,	H	W	--	P	N	--	N,	--	T	M	
$C_v(T_e)$							G				

Harr, M. E., Influence of Vehicle Speed on Pavement Deflections", Proc., HRB, Vol. 41, pp. 77-82 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v,	V	--	--	N	--	--	D_{u-p}	S,	--	--	
$C_v(T_v)$							D_t	M			

Harr, M. E. and Lovell, Charles W., "Vertical Stresses Under Certain Axisymmetrical Loadings", Highway Research Record No. 39, HRB, pp. 68-77 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	*	S	--	--	

* Loadings (no shear at surface of contact) considered are: general axisymmetrical loading, uniformly loaded circular area, circular area with parabolic loading function, circular area with conical loading function.

Herner, Raymond C., "Progress Report on Load-Transmission Characteristics of Flexible Paving and Base Courses", Proc., HRB, Vol. 31, pp. 101-120 (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	S_c, A	PL, S_c	-- PL	S_r^c, S_s, S_d	S	--	--	

IV$_b$. Position of load specified.

Heijnen, W. J., Batteke, J. P. H., "Traffic Tests Undertaken on Concrete Pavements at Schiphol Airport II", Proc., Fifth ICSMFE, Vol. 2, pp. 239-244 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	S_c	--	S_d, S_s, D_d	M, S	T_{gr}	--	

Herner, Raymond C., "Effect of Base-Course Quality on Load Transmission Through Flexible Pavements", Proc., HRB, Vol. 34, pp. 224-233 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S_c, S_{fc}, SL, A	PL	S_s, S_r	S	--	--	

IV_b. Position of load specified.

Heukelom, W., and Foster, C. R., "Dynamic Testing of Pavements", Journal of Soil Mechanics and Foundations Division, ASCE, Part 1, Vol. 86, pp. 1-28 (Feb. 1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e, E	H N	-- N	-- N	A, S	S	S	V, S_u^c	S	T_o	--	

III. Results of tests on numerous types of soil reported.

Heukelom, W., and Foster, C. R., "Dynamic Testing of Pavements", *Journal of the Soil Mechanics and Foundations Division*", ASCE, part 1, Vol. 86, pp. 1-28, Feb., 1960.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e,	H	--	--	A,	S	S	V	S	T_o	--	
E	N	N	N	S			S_u^c				

III. Results of tests on numerous types of soil reported.

Heukelom, W. and Klomp, A. J. G., "Dynamic Testing as a Means of Controlling Pavements During and After Construction", Proc., ICSDAP, pp. 667-679 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	*	*	*	V	S	T_o	M_o	

* Properties (dynamic E, elastic stiffness, etc.) of many materials reported

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Hewitt, William L., "Analysis of Stresses in Flexible Pavements and Development of a Structural Design Procedure", Bull. 269, HRB, pp. 66-74 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{cc}	H, P-C	H, P-C	--	A, S_f, S_c	S_f,	--	S_u^c	S	--	--	

Highway Research Board, "The AASHO Road Test", Special Reports 61A-61G (seven reports), HRB, 1962.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A											

Highway Research Board, "The AASHO Road Test: Proceedings of a Conference Held May 16-18, 1962, St. Louis, Mo.", Special Report 73, HRB, 1962.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A											

Hittle, J. E. and Goetz, W. H., "Factors Influencing the Road-Carrying Capacity of Base-Subgrade Combination", Proc., HRB, Vol. 26, pp. 521-543 (1946)

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_c, S_{cf}	S	--	S_r^c	S	--	M_o	

Hogg, A. H. A., "Equilibrium of a Thin Plate, Symmetrically Loaded, Resting on an Elastic Foundation of Infinite Depth", Philosophical Magazine and Journal of Science, Vol. 25, Seventh Series, pp. 576-582 (1938).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S^r, S_u^c	S	--	--	

Holl, D. L., "Shearing Stresses and Surface Deflections due to Trapezoidal Loads", Proc., HRB, Vol. 19, pp. 409-423 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	R_f	--	N	--, R	--	S_e^t, S_e^r, S_e^{tr-s}, S_e^{tr-u}, S_e^g	S	--	--	

Holl, D. L., "Stress Transmission in Earths", Proc., HRB, Vol. 20, pp. 709-721 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	E	--	--	N	--	--	S^n, S_t, S_1, S_u^c, S_c^c, S_u^r, S_t^r	S	--	--	

Housel, W. S., et. al., "Discussion on Flexible Surfaces", Proc., HRB, Vol. 20, pp. 314-332 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Article presents comments on the following papers contained in Proc., HRB, Vol. 20 (1940).

1. "Wheel Load Stress Distribution Through Flexible Type Pavements", Spengler and Ustrud.

2. "Suggested Method of Design of Non-Rigid Pavements", Goldbeck.

3. "Required Thickness of Asphalt Pavements in Relation to Subgrade Support", Hubbard and Field.

4. "Soil Displacement Under Circular Loaded Areas", Palmer and Barber.

Hubbard, P. and Field, F. C., "Required Thickness of Asphalt Pavement in Relation to Subgrade Support", Proc., HRB, Vol. 20, pp. 271-278 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	A	S	--	S^c	S	--	--	

Hveem, F. N. and Sherman, G. B., "Thickness of Flexible Pavements by the California Formula Compared to AASHO Road Test Data", Highway Research Record No. 13, HRB, pp. 142-166 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A, S											

I. AASHO Road Test results and California design equation compared

Note: Sections include "The Pavement Problem". and "Factors to be Considered in a Design Formula". Figure 2 shows variables affecting performance of an asphalt pavement.

Hveem, F. N., "Pavement Deflections and Fatigue Failures", Bull. 114, HRB, pp. 43-87 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A,	S_c	S_s	S_s,				
				P		S_f	S_d,	S	T_o	M_o	

D_s,

D_d

Hveem, F. N., and Sherman, G. B., "Thickness of Flexible Pavements by the California Formula Compared to AASHO Road Test Data", Highway Research Record No. 13, HRB, pp. 142-166 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A, S											

I. AASHO Road Test results and California design equation compared.

Note: Sections include "The Pavement Problem", and "Factors to be Considered in a Design Formula". Figure 2 shows variables affecting performance of an asphalt pavement.

Ivanov, N., Krivisski, A., Tcherkassov, I , Babkov, V, Biroulia, A., "Certain Aspects of the Design of Flexible Pavements", Proc., Fifth ICSMFE, Vol. 2, pp. 245-250 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	N	N	--	N	S	--	D_f, s^a	M, S	--	M_o	

Ivanov, N. N., Birulya, A. K., Babkov, V. F., Puzakov, N. A., "Flexible Pavement Design", *Proc.*, Fourth ICSMFE, Vol. 2, pp. 120-125 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	N	--	A	S	--	S_d	S	T_o	M_o	

Jeuffroy, G. and Bachelez, J., "Note on a Method of Analysis for Pavement", *Proc.*, ICSDAP, pp. 300-309 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1	H	E	E	A	N	N	S_s^c, S_d^e	S	--	--	

Jones, A., "Tables of Stresses in Three-Layer Elastic Systems", Bull. 342, HRB, pp. 176-215 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	N	N	N	S_c^u	S	--	--	

Jones, R., and Whiffin, A. C., "A Survey of Dynamic Methods of Testing Roads and Runways", Bull. 277, HRB, pp. 1-8 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Jones, R., "Measurement and Interpretation of Surface Vibrations on Soil and Roads", Bull. 277, HRB, pp. 3-29 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E,	E,	--,	--,	A,	S	S	V	S	*	*	
$C_v(T_1{}^e$	E,	E,	--	S							
	E,	E	E								

III. Results of experiments on various soils reported.

* Results on same site, various times of the year, reported.

King, K. H., Pitt, L. C., "Tests to Determine the Behavior of Rail-Track Formations on Various Soil Subgrades with Particular Reference to Clays", Proc., Fourth ICSMFE, Vol. 2, pp. 128-133 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_f	R	--	D_{u-p}	S	--	M_o	

ERROR made in page numbering - Pages 56 - 65.

Kondner, R. L., Krizek, R. J., "Factors Influencing Pavement Performance", a report submitted to HRB, Oct, 1964.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A, *											

* Results from the Hybla Valley Test Program also considered.

Krynine, D. P., "Report of Committee on Stress Distribution in Soils" and, "Study of Stress Distribution in Soils from 1920 to 1940", Proc., HRB, Vol. 21, pp. 531-540 (1941).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Kuhn, S. H. and Rigden, P. J., "Measurement of Viscoelastic Properties of Bitumens Under Dynamic Loading", Proc. HRB, Vol. 38, pp. 431-458 (1959).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, T_v	V	--	--	AC, T	--	--	V	--	T_o	--	

Larew, H. G. and Leonards, G. A., "A Strength Criterion for Repeated Loads", Proc., HRB, Vol. 41, pp. 529-556 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_s, S_f, S_{cf}	--	--	R_t	--	--	--	

Lattes, R., Lions, J. L. and Bonitzer, J., "Use of Galerkin's Method, for the Study of Static and Dynamic Behavior of Road Structures", Proc., ICSDAP, pp. 530-536 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1	V	E, E	V	N	N,N	N	*	S	--	--	

II_b. Road assumed to be four-layer system; two middle layers assumed elastic.

* Static and dynamic loads (no further specifications) considered.

Lawton, Warren L., "Static Load Contact Pressure Patterns Under Airplane Tires", Proc., HRB, Vol. 36, pp. 233-239 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	PL	--	--	S_s	S	--	--	

IV_b. Position of load specified.

Livneh, M. and Shklarsky, E., "The Bearing Capacity of Asphaltic Concrete Carpets Surfacing", Proc., ICSDAP, pp. 345-357 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	P-C	--	A	N, P	--	S^r	S	--	--	

IV_a. Static loads of infinite and finite length considered. Load may be vertical or inclined; some consideration of braking stresses; some consideration of dynamic loads.

Laxton, H., Beavus, H. M. and McNicholl, M. D., "A Procedure for Evaluating the Influence of the Moisture Content of the Subgrade on the Thickness Required for Flexible Pavements of Airfields", Proc., Second ICSMFE, Vol. 2, pp. 218-222 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	N	S_f	--	P_{cbr}	S	--	M_o	

Maclean, D. J. and Armstrong, M. D., "The Design of Road Foundations", Proc., Third ICSMFE, Vol. 2, pp. 118-121 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	A, P	S_s, S_f, S_c	--	*	S	--	M_o	

* Performance of roads subjected to highway traffic observed.

Maxwell, A. A., "Non-Destructive Testing of Pavements", Bull. 277, HRB, pp. 30-36 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	E	E	E	A	S_{cf}	S_{cs}	V	S	--	--	

McCarthy, L. E., "Applications of the Mohr Circle and Stress Triangle Diagrams to Test Data Taken With the Hveem Stabilometer", Proc., HRB, Vol. 26, pp. 100-123 (1946).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Two-part paper. In part one, Mohr"s circle developed; various failure theories discussed. In part two, another graphical stress analysis is presented.

McDowell, C., "Wheel-Load-Stress Computations Related to Flexible Pavement Design", Bull. 114, HRB, pp. 1-20 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	E	E	--	N	N	--	S_s^c	S	--	--	

McFadden, G., "Airfield Pavement Design of the Corps of Engineers", Proc., ASCE, Vol. 80, Separate 458 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Corps of Engineers design procedures.

McLeod, Norman W., "The Rational Design of Bituminous Paving Mixtures", Proc., HRB, Vol. 29, pp. 107-159 (1949).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	N	N	A	N	N	S_u^s, D_f, D^n	S, M	--	--	

McLeod, Norman W., "Rational Design of Bituminous Paving Mixtures with Curved Mohr Envelopes", Proc., AAPT, Vol. 21, pp. 349-437 (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	--	--	A	N	N	S_u^s, S_s, M	S	--	--	

McLeod, Norman W., "Influence of Tire Design and Vehicle Mobility", Proc., HRB, Vol. 31, pp. 121-147 (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	P-C	--	A, S_f, S_c	N, S_f	--	S_s^e, M, S_u^s, D_f	S	--	--	

McLeod, Norman W., "The Design of Bituminous Mixtures with Curved Mohr Envelopes", Proc., AAPT, Vol. 22, pp. 238-283 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	--	--	A	N	N	S_u^s, S_s	S	--	--	

McLeod, N. W., "Airport Runway Design and Evaluation in Canada", Proc., Third ICSMFE, Vol. 4, pp. 122-127 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	N	N	--	R^c	S	--	--	

McLeod, Norman W., "Some Basic Problems in Flexible-Pavement Design", Proc., HRB, Vol. 32, pp. 90-118 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	P-C	--	A	S	--	S_u^s	S	--	--	

McLeod, N. W., "Relationships Between Deflection, Settlement and Elastic Deformation for Subgrades and Flexible Pavements Provided by Plate Bearing Tests at Canadian Airports", Proc., Fourth ICSMFE, Vol. 2, pp. 151-157 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_c, S_f, A	S_f, S_c	--	R^c	S	--	--	

McLeod, N. W., "Relationships Between Applied Loads, Surface Deflections, Traffic Volumes, and Thickness of Flexible Pavements", Proc., Fifth ICSMFE, Vol. 2, pp. 277-281 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S	S	S_r	S	--	--	

McLeod, Norman W., "Some Notes on Pavement Structural Design", Highway Research Record No. 13, HRB, pp. 66-141 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_1)$	H	H	--	A, P	A, S_c, S_f	--	S_u^c	S	T_o	M_o	

II. Burmister's results compared with emperically derived relationship.

McMahon, T. F. and Yoder, E. J., "Design of a Pressure-Sensitive Cell and Model Studies of Pressures in a Flexible Pavement Subgrade", Proc., HRB, Vol. 39, pp. 650-682 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$ $C_v(T_1^e$	H, N	H	--	S_c, S_f	S_f	--	S^c	S	--	--	

Mellinger, Frank M., Sale, James P., Wathen, Thurman R., "Heavy Wheel Load Traffic on Concrete Airfield Pavements", Proc., HRB, Vol. 36, pp. 175-189 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	W	--	P	S_f, S_{cs}	--	D_{tw}	M, CH	--	--	

Middlebrooks, T. A., and Bertram, G. E., "Field Investigation for Flexible Pavement Design", Proc., HRB, Vol. 21, pp. 137- 141 (1941).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	*	N	S_r^c	S	--	--	

* Bituminous stabilized base course.

Monismith, Carl L. and Secor, Kenneth E., "Viscoelastic Behavior of Asphalt Concrete Pavements", Proc., ICSDAP, pp. 476-498 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v, $C_v(T_v)$ S	V	W	--	A	*	--	S^c	S	T_o	--	

I. Short survey of literature presented concerning viscoelastic properties of asphalt cement and concrete and the viscoelastic behavior of layered systems..

* Experimental base comprised of small coil springs.

IV_a. Static loads applied to test slab; rheologic behavior of the asphalt concrete mixture determined from other tests.

Nascimento, U., Simoes, A., "Relation Between CBR and Modulus of Strength", Proc., Fourth ICSMFE, Vol. 2, pp. 166-168 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	H	--	--	R, S_s, S_e	--	--	S_n^c	S	--	--	

IV_a. CBR plunger used in loading tests.

Nascimento, U., Seguro, J. M., Da Costa, E., Pinela, S., "A Method of Designing Pavements for Roads and Airports", Proc., Fifth ICSMFE, Vol. 2, pp. 283-288 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	H	H	N	N	N	S^c	S	--	--	

Nevitt, H. G., "A Mathematical Analysis of Some Phases of the Flexible Surface Design Problem", Proc., HRB, Vol. 23, pp. 149-154 (1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
D, T_1^{ce}	C, S	N	--, N	N	N	--, N	S_u^c, S_n	S	--	--	

Nichols, F. P., Jr., "Deflections as an Indicator of Flexible Pavement Performance", Highway Research Record No. 13, HRB, pp. 46-65 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S, S_{ce}	S, S_{ce}	S_d	S	T_o	--	

IV_a. Creep speed deflections measured.

V_a. Temperature range recorded in data.

Nijboer, L. W. and Van Der Poel, C., "A Study of Vibration Phenomena in Asphaltic Road Constructions", Proc., **AAPT**, Vol. 22, pp. 197-237 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S	S	V. D_s, D_d	S	T_o	--	

IV_a. Road vibration machine discussed.

Nijboer, L. W., "Mechanical Properties of Asphalt Materials and Structural Design of Asphalt Roads", Proc., HRB, Vol. 33, pp. 185-200 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Painter, A., "Analysis of AASHO Road Test Asphalt Pavement Data by the Asphalt Institute". *Highway Research Record No. 71*, HRB, pp. 15-38 (1965).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A											

Palmer, L. A., "Stresses Under Circular Loaded Areas", *Proc.*, HRB, Vol. 19, pp. 397-407 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S_u^c	S	--	--	

Palmer, L. A., and Barber, E. S., "Soil Displacement Under a Circular Loaded Area", Proc., HRB, Vol. 20, pp. 279-286 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	H, --	--	A, S_f, S_c	S_f, S_c	--	S_u^c	S	--	--	

Palmer, L. A. and Thompson, J. B., "Pavement Evaluation by Loading Tests at Naval and Marine Corps Air Stations", Proc., HRB, Vol. 27, pp. 125-143 (1947).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, $C_v(T_e)$	N, H	N, H	N, P-C, H	P, A	*	*	S^c	S	--	M_o	

* Many combinations of materials reported.

Palmer, L. A., "Special Procedures for Pavement Design", Trans., ASCE, Vol. 119, pp. 542-560 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

I. Navy method of pavement design discussed.

Papazian, Hratch, "The Response of Linear Viscoelastic Materials in the Frequency Domain With Emphasis on Asphaltic Concrete", Proc., ICSDAP, pp. 454-463 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_v)$	V	--	--	A	--	--	*	--	T_o	--	

* Sinusoidal-stress dynamic tests and constant-stress static tests on laboratory asphaltic concrete test specimens discussed.

Paxson, G. S., "Factors Influencing the Stress in Concrete Pavement from Applied Loads", Proc., HRB, Vol. 25, pp. 59-69 (1938).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	H	W	--	P	N	--	S^r, S^e	I	--	--	

Peattie, K. R., "Stress and Strain Factors for Three-Layer Elastic Systems", Bull. 342, HRB, pp. 215-253 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	N	N	N	S_c^u	S	--	--	

Peattie, K. R., "A Fundamental Approach to the Design of Flexible Pavements", Proc., ICSDAP, pp. 403-411 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	A	S_c	N	*, V	S	T_o	--	

* Load is assumed to be applied uniformly over a circular area for the purposes of calculating stresses and displacements; time for which the load is applied to the road is considered.

IV_a. Vibrational tests proposed for determination of layer properties.

Philippe, R. R. and Mellinger, F. M., "Structural Behavior of Heavy-Duty Concrete Airfield Pavements", Proc., HRB, Vol. 31, pp. 87-100 (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	W	P	N, S_f	S_f	D_s, D_{twt}	M, S	T_{gr}	--	

Pickett, Gerald, "Stress Distribution in a Loaded Soil with Some Rigid Boundaries", Proc., HRB, Vol. 18, Part II, pp. 35-48 (1933).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	R_f	--	S_f	R	--	S^r, S_u^s, S_u^c	S	--	--	

Pickett, G. and Ray, G. K., "Influence Charts for Concrete Pavements", Proc., ASCE, Vol. 76, Separate 12 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W, H	--	P	N	--	S^a	I, E	--	--	

Pister, K. S. and Westmann, R. A., "Analysis of Visoelastic Pavements Subjected to Moving Loads", Proc., ICSDAP, pp. 522-529 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v	V	W	--	N	N	--	$D^r(C)$	M, S	T_o	--	

II_a. Analysis concerned with infinite, viscoelastic beam.

III_a. Material properties represented by spring dashpot system.

IV_b. Position specified.

Pister, Karl S., and Monismith, Carl L., "Analysis of Viscoelastic Flexible Pavements", Bull. 269, HRB, pp. 1-16 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v	V	W, --	--	A	N, --	--	*, S^r, **	S	T_o	--	

* Time-dependent load, q(x, t), considered.

** Repeated compressive loading of an unconfined cylinder.

Popov, E. P., "Successive Approximations for Beams on an Elastic Foundation", Proc., ASCE, Vol. 76, Separate 18 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	N	S	--	*	S	--	--	

* Various beam loadings imposed.

Reddy, A. S., Leonards, G. A., Harr, M. E., "Warping Stresses and Deflections in Concrete Pavements: Part III", Highway Research Record No. 44, HRB, pp. 1-24 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v,	H	V	--	P	N	--	*	S	T	M	

* External forces on slab are gravity and/or a uniformly distributed normal load.

V. Non-linear variations considered.

Schiffman, Robert L., "General Analysis of Stresses and Displacements in Layered Elastic Systems", Proc., ICSDAP, pp. 365-375 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	N	N	N	*	S	--	--	

* Loads considered are:

(1) General asymmetric system
(2) Flexible
(3) Rigid
(4) Tangential
(5) Slightly inclined, rigid

Sanborn, J. L., "An Experimental Analysis of Transient Vehicle Loads and Response of Flexible Pavements", Ph.D. Thesis, Purdue University, 1965.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	A, S_c	S_f	D_{d-s}	M, S	--	--	

From the conclusions: "Displacements and stresses within the pavements varied with vehicle velocity as well as with pavement stiffness. Subgrade displacements did not show significant variation."

Schiffman, R. L., "The Numerical Solution for Stresses and Displacements in a Three-Layer Soil System", Proc., Fourth ICSMFE, Vol. 2, pp. 169-173 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	H	H	N	N	N	S_u^c	S	--	--	

Schnitter, G. and Jenatsch, R., "Designing Flexible Road Pavements", Proc., ICSDAP, pp. 537,547 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S,	H	--, H	--, H	N	N	N	S^c, *	S	T_o	M_o	

* Design for dynamic situation considered.

Seed, H. B., Chan, C. K., Lee, C. E., "Resilience Characteristics of Subgrade Soils and Their Relation to Fatigue Failures in Asphalt Pavements", Proc., ICSDAP, pp. 611-636 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_f, S_{sf}	--	--	R_t, R^c	S	--	M_o	

Seed, H. B., and Chan, D. K., "Effect of Stress History and Frequency of Stress Application on Deformation of Clay Subgrades Under Repeated Loading", Proc., HRB, Vol. 37, pp. 555-575 (1958).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_{sf}, S_c	--	--	R_t	--	--	M_o	

Seed, H. B., Chan, Clarence K., and Monismith, Carl L., "Effects of Repeated Loading on the Strength and Deformation of Compacted Clay", Proc., HRB, Vol. 34, pp. 541-558 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_{sf}	--	--	R_t	--	--	--	

Skok, Eugene L., Jr., and Finn, Fred N., "Theoretical Concepts Applied to Asphalt Concrete Pavement Design", Proc., ICSDAP, pp. 412-440 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	E	E	A	S_c	N	S^c	S	T_o	--	

I. Elastic theory (three-layers) applied to AASHO and WASHO Road Test data.

Shook, J. F., Fang, H. Y., "Cooperative Materials Testing Program at the AASHO Road Test", Special Report 66, HRB, pp. 59-102 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A											

Sinitsyn, A. P., Glushkov, G. I., Rajev-Bogoslavsky, B. S., Manuelov, Mikhailov, A. V., Tolmachev,I. N., Strength Tests of Slabs on Elastic Foundations Under Dynamic Load", Proc., Fifth ICSMFE, Vol. 2, pp. 321-325 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	E	N	--	P, P_{ps}	S	--	D^t, S^a	M, E	--	M_o	

Smith, E. B., "Impact and Static Loads on Road Slabs", Proc., HRB, Vol. 4, pp. 42-44 (1924).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	N	--	S_s, I	E, C	--	--	

Smith, E. B., "Wheel Load and Impact in Pavement Design", Proc., HRB, Vol. 8, pp. 187-192 (1928).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	N	--	S_m, S_s, S_d, I	S	--	--	

Sowers, G. F., Vesic, A. B., "Stress Distribution Beneath Pavements of Different Rigidities", Proc., Fifth ICSMFE, Vol. 2, pp. 327-331 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	H	H	A	S_c, S_{ce}	S_{cs}	S_s, S_d	S	--	--	

Sowers, George F. and Vesic, Aleksandar, "Vertical Stresses in Subgrades Beneath Statically Loaded Flexible Pavements", Bull. 342, HRB, pp. 90-123 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$,	H,	--,	--,	A	S_s,	S_s	S_s,	S	--	M_o	
$C_v(T_1^e)$	H,	H	--		S_c,		S_d				

S_{ce},

A

IV_a. Duals included single axle and tandem axle applications; repetitive application of single tire load also reported.

Spangler, M. G., "Stresses in Concrete Pavement Slabs", Proc., HRB, Vol. 15, pp. 122-146 (1935).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	P	S_f	--	S_u^c	C	T_g	--	

Spangler, M. G., and Lightburn, F. E., "Stresses in Concrete Pavement Slabs", Proc., HRB, Vol. 17, pp. 215-230 (1937).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, $C_v(T_e)$	E	E, W	--	P	S_f	--	S^c, S_s^r, S_d^r	C	T_g	M_g	

Spangler, M. G., and Ustrud, H. O., "Wheel Load Stress Distribution Through Flexible Type Pavements", *Proc.*, HRB, Vol. 20, pp. 235-257 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	S_c, S_{cf}	S_f	S_c	S_s	S	--	--	

Spangler, M. G., "Wheel Load Stress Distribution Through Flexible Type Pavements", Proc., HRB, Vol. 21, pp. 110-117 (1941).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_{cf}, S_c	S_{cf}	--	S_s, S_n^c, S^e	S	--	M_o	

Spangler, M. G., "The Structural Design of Flexible Pavements", Proc., HRB, Vol. 22, pp. 199-219 (1942).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A, S	S	S	S^n, S_s	S	--	M_o	

Spangler, M. G., "Stresses in the Corner Region of Concrete Pavements", Bull. 157, Iowa Engineering Experiment Station, Vol. 41, No. 14 (1942).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, $C_v(T_e)$	H	W	--	P	S_f	--	S_c	C	T_g		

Stratton, J. H., "Military Airfields; A Symposium - Construction and Design Problems", Trans., ASCE, Vol. 110, pp. 669-696 (1945).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Corps of Engineers airfield pavement design procedures.

Subbaraju, B. H., "Model Study of Stresses in Asphalt Pavements", Proc., ICSDAP, pp. 324-331 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	A	S_s	--	*	S	--	--	

* Load applied to the model asphalt slab through a small, hard rubber wheel (vertical or inclined) or through the wheel resting on a small, circular steel bearing plate.

Teller, L. W. and Buchanan, J. A., "Determination of Variation in Unit Pressure Over the Contact Area of Tires", Public Roads, Vol. 18, December 1937, pp. 195-198.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	*	--	--	S_s	S	--	--	

* Tire loaded while resting on a brass bar which in turn rests on a steel plate.

Teller, L. W., and Sutherland, Earl C., "The Structural Design of Concrete Pavements, Parts 1, 2, 3, 4, and 5", *Public Roads*, Vols. 16, 17, 23 (October, November, December, 1935, October 1936, April, May, June, 1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	P	S_f	--	S^c, S^{sc}	C, I, E	T, T_o	M, M_o	

Teller, L. W., "Effects of Loads on Pavements as Indicated by Stress Measurements", Proc., HRB, Vol. 7, pp. 172-175 (1927).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	S	--	D_t, S_s, I	I, E, C, M	--	--	

Thompson, William E., "Analysis of Dynamic Behavior of Roads Subject to Longitudinally Moving Loads", Highway Research Record No. 39, HRB, pp. 1-24 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e, T_v	H, V	E	--	N	N	--	D^r(c)	S, M	--	--	

Tschbotarioff, G. P., and McAlpin, G. W., "Vibratory and Slow Repetitional Loading of Soils", Proc., HRB, Vol. 26, pp. 551-562 (1946).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	N	--	--	S_c, S_f	--	--	PP, V	S	--	--	

Turnbull, W. J., Maxwell, A. A., Ahlvin, R. G., "Stresses and Deflections in Homogeneous Soil Masses", *Proc.*, Fifth ICSMFE, Vol. 2, pp. 337-345 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	E	--	--	S_{fs} S_c	--	--	S_u^c	S	--	M_o	

Turnbull, W. J., "Mathematical Expression of the CBR (California Bearing Ratio)", Proc., Fourth ICSMFE, Vol. 2, pp. 178-180 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	N	N	N	N	N	N	S_s^c	S	--	--	

Van der Veen, C., "Loading Tests on Concrete Slabs at Schiphol Airport", Proc., Third ICSMFE, Vol. 2, pp. 133-142 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	H, W	H	P, P_p	S_c	S_f	R^c	I, E, C	--	--	

van der Poel, C. "Vibration Research on Road Constructions", STP No. 156, ASTM, pp. 174-185 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_1^v)$	*	*	*	N	N	--	V	S	--	--	

* "Resistivity" of the road under the load is represented by a spring and dashpot in parallel (Voigt model).

III. Tests on various types of constructions reported. A "tar-macadam" subbase is specifically mentioned.

Van der Veen, C., "Loading Tests on the Airfield at Beck", Proc., Fourth ICSMFE, Vol. 2, pp. 186-188 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	R	S	S_r^c	S	--	M_o	

Walker, R. D., Yoder, E. J., Spencer, W. T., and Lowry, R., "Significance of Layer Deflection Measurements", Bull. 321, HRB, pp. 63-81 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	--	--	A	S_c	S_f	S_d^c	S	--	--	

Vesic, A., "Beams on Elastic Subgrade and the Winkler's Hypothesis", Proc., Fifth ICSMFE, Vol. 1, pp. 845-850 (1961).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	*	S, S_{fs}	--	S^n	S	--	--	

* Steel beam

Vesic, A. S., Domaschuk, L., "Extension of Road Test Performance Concepts-Flexible Pavements", a report submitted to HRB, Aug. 31, 1964.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A, S, $C_v(T_1^e)$	H	H	H	A	S	S	S_s, S_d, S^c	S	*	*	

* Seasonal variations in stress considered.

Westergaard, H. M., "Computation of Stresses in Concrete Roads", *Proc.,* HRB, Vol. 5, Part I, pp. 90-112 (1925).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_ϵ	H	W	--	P	N	--	S_s^c, S_u^{sc}, S_m	I, E, C	--	--	

Westergaard, H. M., "Stresses in Concrete Pavements Computed by Theoretical Analysis", Public Roads, Vol. 7, April 1926, pp. 25-35.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S^n, S_u^c, S_u^{sc}, S_s^c, S_d^c	I, E, C	--	--	

Westergaard, H. M., "Analysis of Stresses in Concrete Pavements due to Variations in Temperature", Proc., HRB, Vol. 6, pp. 201-215 (1926).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	*	--	T	--	

* No external loads considered in analysis.

Westergaard, H. M., "What is Known of Stress", Engineering News Record, Vol.18, January 7, 1937, pp. 26-29.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e, S, T_{sm}	H	W	--	P	N	--	S^n, S_u^{sc}, S_u^e	C, I	T_o	--	

Westergaard, H. M., "Stresses in Concrete Runways of Airports", *Proc.*, HRB, Vol. 19, pp. 197-205 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S_u^c	I	--	--	

Westergaard, H. M., "Stress Concentrations in Plates Loaded Over Small Areas", *Trans.*, ASCE, Vol. 108, pp. 830-886 (1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--, W	--	N, P	N	--	S^n, S_d^e, *	I	--	--	

* Coefficients determined for loaded areas of various geometric shapes (circles, strips, ellipse, triangle, polygon).

Westergaard, H. M., "New Formulas for Stresses in Concrete Pavements of Airfields", Trans., ASCE, Vol. 113. pp. 425-444 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S_s^e, S_d, S^a	I, E	--	--	

Whiffin, A. C., and Lister, N. W., "The Application of Elastic Theory to Flexible Pavements", Proc., ICSDAP, pp. 499-521 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e, $C_v(T_1^e)$	H	H	H	A	*	*	S_u^c, D_t	S, M	T_o	--	

III_a. Tar surface also considered.

* Various materials considered.

Wiseman, J. F., Harr, M. E., Leonards, G. A., "Warping Stresses and Deflections in Concrete Pavements: Part II", *Proc.*, HRB, pp.157-172 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e, $C_v(T_e)$	H	W	--	P	N, S_{ce}		N, G	--	T	M	

Wilson, G., and Williams, G. M. J., "Pavement Bearing Capacity Computed by Theory of Layered Systems", Proc., ASCE, Vol. 76, Separate 16, pp. 1-17 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e, S	H	H, P-C	--	A, P	S_c, S_f	--	S_u^c	S	--	--	

Woods, K. B., "Influence of Heavy Loads on Pavement Design Trends", Proc., ASCE, Vol. 76, Separate 23, pp. 1-18 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Paper contains large bibliography.

Yoder, E. J., Milhous, R. T., "Comparison of Different Methods of Measuring Pavement Condition", a report submitted to HRB, Feb. 29, 1964.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E,	N	N	N	A,	N	N	**	S	--	--	
A				P,							
				*							

* Overlay pavements considered also.

** Loads consisted of test equipment which obtained objective measurements used in determining pavement condition.

APPENDIX E

PROJECT STATEMENT

and

RESEARCH PROSPECTUS

PROJECT STATEMENT

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM Project 1-4

Highway Research Board
National Academy of Sciences-National Research Council

1962-63

Research Project Title:

Extension of Road Test Performance Concepts.

General Problem Area:

Translation of AASHO Road Test Results to Local Conditions.

Research Problem Statement:

It is recognized that results obtained at the AASHO Road Test reflect only the prevailing ambient conditions and properties of the materials indigenous to Ottawa, Illinois. It is desired to relate the wealth of information resulting from this test to other locations.

There exist in the engineering literature many theories that attempt to describe, from a mechanistic point of view, the action and reaction of pavements subjected to various loadings.

In the main, they represent solutions of particular problems (or particular parts of the overall problem of performance vs. design) many of which, because of the high cost of performance testing, have never been properly evaluated.

Other solutions exist, again for parts of the overall problem, which have been verified but have received but little attention from highway designers.

Additional work is warranted to establish new and test old theories that involve fundamentals of materials and pavement behavior. Extension of the successful models for stress prediction, for example, is needed to relate the engineering properties of materials and structural elements of pavements directly to pavement performance.

In the light of the findings of the Road Test a comprehensive overview of all theories is needed to determine relationships which are necessary and sufficient for a broad and adequate description of pavement performance.

Objective:

To examine existing hypotheses and to develop new hypotheses of pavement performance as related to fundamental principles of engineering mechanics and materials science and to test these hypotheses with data at hand from the AASHO Road Test and elsewhere.

RESEARCH PROSPECTUS

PROJECT NUMBER AND TITLE: NCHRP Project 1-4, "Extension of Road Test Performance Concepts"

DATE SUBMITTED: April 30, 1963

SUBMITTED BY: School of Civil Engineering, Purdue University, Lafayette, Indiana

MAJOR SUBDIVISION THAT WILL CONDUCT RESEARCH: School of Civil Engineering, Purdue University, Lafayette, Indiana

PRINCIPALS:

1. Professor Milton E. Harr
   Phone: 92-3510
   School of Civil Engineering
   Purdue University
   Lafayette, Indiana

2. Professor John F. McLaughlin
   Phone: 92-2762
   School of Civil Engineering
   Purdue University
   Lafayette, Indiana

BIOGRAPHICAL INFORMATION AND SUPPLEMENTAL STAFF:

1. Harr, Milton E.: Born Massachusetts 1925; Professor of Soil Mechanics; BSCE Northeastern 1949, MSCE Rutgers 1955, Ph.D. Purdue 1958. Author of the book Groundwater and Seepage. Research on concrete pavements, subgrade support characteristics, and various phases in soil mechanics. Experience includes teaching graduate and undergraduate courses in soil mechanics and engineering materials. Member ASCE, Sigma Xi, Chi Epsilon.

2. McLaughlin, John F.: Born New York 1927; Professor of Civil Engineering; BCE Syracuse 1950, MSCE Purdue 1953, Ph.D. Purdue 1957. Professional Engineer, Kansas. Research on bituminous materials and mixtures, concrete and mineral aggregates. Experience includes

teaching graduate and undergraduate courses in highway engineering and design. Member HRB (Dept. of Materials and Construction), A-6 (Chairman), B-1, B-3, D-1, ACI, ASTM, ARBA, NSPE, Tau Beta Pi, Sigma Xi.

3. Head, William J.: Born Texas 1938; Instructor and Ph.D. Candidate in Civil Engineering; BSCE New Mexico 1960, MSCE Purdue 1962. Engineer-In-Training, New Mexico. Research for HERPIC. Member NMSPE.

4. Berk, Morris III: Born Illinois 1939; Graduate Assistant in Civil Engineering; Engineer-In-Training, Indiana. BA Saint Mary's (Minnesota) 1961, BSCE Purdue 1962. Member ASCE, Tau Beta Pi, Chi Epsilon.

OTHER SUPPORT: None

ORGANIZATION:

It is intended that Mr. William J. Head and Mr. Morris Berk III will be placed half-time on this research project under the direction of Professors Milton E. Harr and John F. McLaughlin.

EQUIPMENT AND FACILITIES:

The University Libraries offer in all some 570,000 volumes housed in the General Library, in 20 departmental or special libraries, and in several deposit collections. The effectiveness of these facilities is extended through a program of Inter-Library Loan. Office space is available in graduate research areas within the School of Civil Engineering. All space requirements are included in overhead charges.

COOPERATIVE FEATURES:

Certain information and data will be requested from AASHO information files.

PROPOSED BUDGET: (Period of August 1, 1963 to March 31, 1964)

I. Salaries and Wages	
A. Principal Investigators	$ 1,900
Professor Milton E. Harr Professor John F. McLaughlin (Approx. 10% time for 8 months)	
B. Graduate Research Assistants	
Mr. William J. Head (Approx. 50% time for 8 months)	2,000
Mr. Morris Berk III	1,840
C. Clerical Assistance	200
	$ 5,940
II. Annuities, Social Security, Workmen's Compensation Insurance, etc.	$ 375
III. Miscellaneous expenses	460
IV. Indirect Charges (54.3% of Salaries and Wages)*	3,225
	$10,000

TIME:

Time of the proposed research would be on an eight (8) calendar month basis beginning August 1, 1963 and ending March 31, 1964.

RESEARCH PLAN:

The prediction of the performance of pavements (and their subsequent design) has been based largely on theories which either contain serious limitations, have been at best only partially verified, or are significantly altered in their application by empirical factors. At the present level of knowledge, the profession knows of no theory that will adequately predict the performance of pavements under the most general conditions.

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* as prescribed by circular A-21

The research plan for Project 1-4, under this prospectus, will attempt to realize the project objectives in three phases. The three phases; to survey or review the literature, to catalogue the existing theories and design procedures, and where possible to check the reliability of these in light of the results of the AASHO Road Test.

The proposed survey of the literature will be an exhaustive study of the body of pertinent scientific and engineering publications. The object will be to obtain a comprehensive understanding of mechanistic models useful in the prediction of pavement performance. Attention will be given to those (perhaps largely neglected) areas of inter-discipline sciences as well as the traditional fields of engineering materials, mechanics, etc.

The second phase of this research plan proposes to catalogue the procedures and theories uncovered during the literature search of the first phase. A concerted effort will be made, during this phase, to identify assumptions and limitations in these theories which would restrict, in total or part, their application under the most arbitrary combinations of loading, materials, and ambient conditions. In establishing this syllabus of theories consideration will also be given to such factors as empirical modifications, time variation of loading and material properties, and changes in the support conditions.

During the third phase of this research plan, the hypotheses studied and catalogued will be reviewed in light of the vast wealth of information obtained at the AASHO Road Test. The prediction of pavement performance obtained from application of these procedures will be studied. When possible, the validity of these predictions will be checked with the observations made at Ottawa, Illinois.

This is the extent of the work proposed under the first contract of Project 1-4. This work does not fully accomplish the overall objectives of the project, but in itself will be of considerable significance to the profession for several reasons. Among other things, this work will provide the profession with a comprehensive critique of the publications on the performance of highway pavements with emphasis on the relative importance of many of the myriad variables. Because the overall objectives of the project are not met by this proposed first contract work, a research plan has been formulated with the expectation that additional funds will be made available for the completion of the project.

In general, this additional work will be orientated toward uncovering the relationships which are necessary and sufficient for a broad and adequate description of pavement behavior. It is hoped that the work accomplished under the first contract will indicate those governing mechanisms which extended and refined will form the strongest link possible for translating experiences from one test site (such as Ottawa, Illinois) to some other location.

SUPPORTING DATA: None